United States
Department of
Agriculture

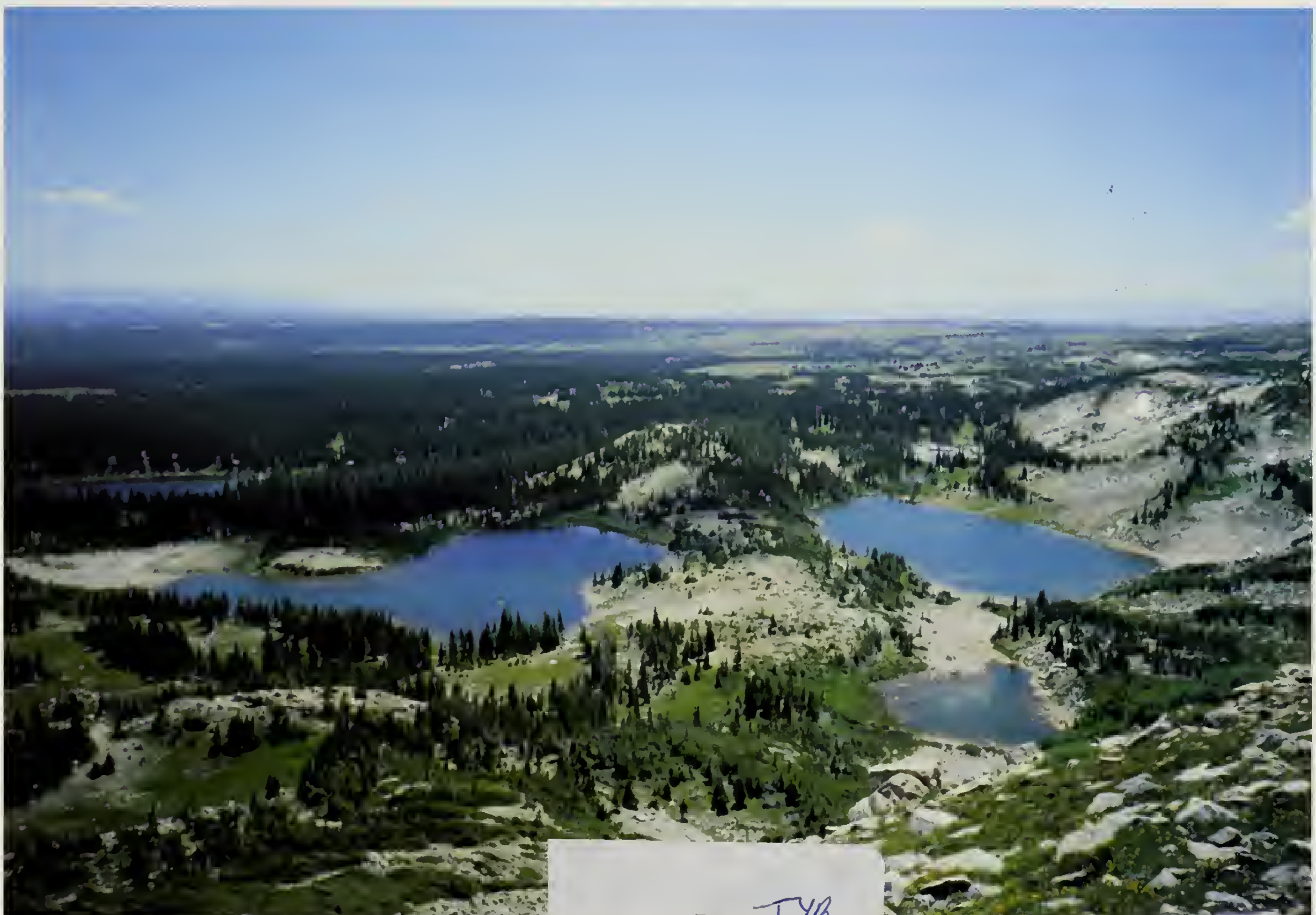
Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

General Technical
Report RM-249

The Glacier Lakes Ecosystem Experiments Site



Musselman, R. C., technical coordinator. 1992. The Glacier Lakes Ecosystem Experiments Site. Gen. Tech. Rep. RM-249. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 94 p.

The Glacier Lakes Ecosystem Experiment Site (GLEES), a 600 ha research watershed at 3200–3400 m elevation in the Snowy Range of SE Wyoming, has been established to examine the effects of atmospheric deposition on alpine and subalpine ecosystems. This document provides preliminary data on the landscape habitats, floristics, geology, soils, aquatics, atmospheric environment, hydrology, snow, and air quality conditions occurring at GLEES. Checklists of vascular plants and plankton, detailed soils descriptions, and maps of geology, soils, vegetation, and topography are provided.

Keywords: Snowy Range, wilderness, subalpine, krummholz, subalpine fir, Engelmann spruce, geology, floristics, landscape, soils, aquatics, atmosphere, meteorology, hydrology, snow, deposition, watershed, monitoring, air quality.

USDA Forest Service
General Technical Report RM–249

July 1994

The Glacier Lakes Ecosystem Experiments Site

Technical Coordinator:
Robert C. Musselman, Plant Physiologist
Rocky Mountain Forest and Range Experiment Station[1]

Contributors:

B.H. Connell	M.A. Conrad
R.G. Dufford	D.G. Fox
J.D. Haines	V.C. Hasfurther
R.W.E. Hopper	H.C. Humphries
G.L. Kerr	B.C. Kondratieff
R.C. Musselman	G. Parks
C.M. Regan	E.A. Rochette
A.W. Schoettle	C.L. Simmons
R.A. Sommerfeld	F.A. Vertucci
P.M. Walthall	J. Wetstein
G.L. Wooldridge	K.F. Zeller

[1] *Headquarters is in Fort Collins, in cooperation with Colorado State University.*

Contents

The Glacier Lakes Ecosystem Experiments Site

245

1. INTRODUCTION

R.C. Musselman, D.G. Fox, A.W. Schoettle, and C.M. Regan
Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado

Background Information

Wilderness ecosystems in the United States are federally mandated and set aside by the Wilderness Act. They are managed to minimize human impact using methods that leave these systems, to the extent possible, in their natural state uninfluenced by manipulation or disruption by humans. Management often involves controlling or minimizing visual impact by enforcing strict use rules such as no roads, motorized or mechanized equipment, structures, or harvesting. In addition to human-caused impacts, natural and anthropogenic environmental stresses affect the rates and magnitudes of natural dynamic processes in natural ecosystems. These stresses can have a large effect on ecosystem structure and function. The Clean Air Act designates federally mandated wildernesses and National Parks as Class I areas to be protected from deterioration from air pollutants. Data are not available to quantify and distinguish between natural and anthropogenic factors that cause changes in wilderness ecosystems.

Wilderness managers are faced with making decisions concerning effects of atmospheric pollutants on Class I wilderness ecosystems. The permitting process for siting a new point-source of pollutants requires an assessment of the potential effects of such a facility on Class I areas. Little data are available to determine the effects of atmospheric deposition on these ecosystems. Background collection of deposition data in these areas is just beginning, and effects of this deposition are largely unknown. In addition, changes in the structure and function of these ecosystems induced by long-term climate change cannot be quantified without baseline data concerning current environmental status of sensitive systems. Prudent management of wilderness ecosystems requires a basic knowledge of the present environmental and biological condition of these systems and an understanding of the basic processes influencing change in these systems.

Research to provide answers to the question of environmental impact of atmospheric deposition or climate change in wilderness sites requires an integrated ecosystem approach involving the study of meteorology, geology, soils, hydrology, limnology, plant ecology, plant physiology, and snow chemistry and physics. These disciplines must be integrated to determine interaction and movement of pollutants, chemicals, or gases among different components of the ecosystem. Research will require measurement of inputs and outputs between tightly defined components of the overall ecosystem, with these components defined as small (e.g., a square meter) terrestrial or soil plots, small sections of a stream, a lake, a small subcatchment, a watershed encompassing a lake, or a group of lakes and their watersheds. Atmospheric and ecosystem processes, and interactions between abiotic and biotic portions of these research units need to be studied, with an important component of these studies being estimation of nutrient budgets. Process-based models will be constructed to integrate individual studies into a system-level understanding of ecosystem processes that can be used to predict the response of the system to potential changes in physical or chemical environment. Long-term baseline monitoring data are important for model development, and detailed process-level studies will provide information for validating the model predictions.

Research involving extensive monitoring and manipulations is not possible in federally mandated wilderness areas, which impose strict limits on means of transport and prohibit installations causing visual impact. The Glacier Lakes Ecosystem Experiments Site (GLEES) has been established in an area that is wilderness-like, but not a federally mandated wilderness, where the research described here can be conducted to provide baseline and experimental data for alpine and subalpine ecosystems. GLEES was selected to represent Class I wilderness areas that might be exposed to atmospheric deposition. It is located on National Forest land and has been managed to preserve its natural state. GLEES is easily accessible all year, yet has received limited human use or impact. GLEES provides a site with habitat similar to wilderness areas in the West but without the restrictions of the statutory designation of a Class I area. These unique characteristics provide an excellent site for extensive alpine and subalpine ecosystem research activity.

GLEES is characteristic of high-elevation alpine/subalpine wilderness sites having massive winter snowpack, harsh climate for terrestrial vegetation, exposed and slow-weathering bedrock, shallow immature soils having low base saturation, and lakes with extremely low acid neutralizing capacity. The deep snowpack typical of these areas accumulates sulfates and nitrates. The aquatic systems are highly sensitive to deposition, since spring snowmelt can bring a pulse of chemicals delivered rapidly to the system. The low inherent buffering capacity of alpine lakes and streams can make them

especially sensitive to this chemical pulse, which can result in drastic changes in the biotic complex of these systems.

Ecosystems exposed to the conditions typical of these sites experience short growing seasons, high winds, cool temperatures with summer frosts, low nutrient supply from soil, and drought conditions after snowmelt. Such environmentally stressed systems are likely to be most sensitive to additional stress from atmospheric pollutants. Global climate change caused by increased atmospheric CO_2 may cause changes in environmental conditions in wilderness ecosystems. In high-elevation ecosystems, dramatic vegetation responses are possible as a result of climate change. For example, the transition zone between alpine and subalpine will likely rise in elevation with a warmer climate. GLEES represents a unique opportunity to study such phenomena, with alpine/forest and terrestrial/aquatic features being dominant at the site.

Site Location

GLEES is an area of approximately 575 ha located at 3200 to 3500 m elevation in the Snowy Range on the Medicine Bow National Forest, 55 km west of Laramie, Wyoming, and 15 km NW of Centennial, Wyoming, at 41°22'30" latitude and 106°15'30" longitude (figs. 1.1–1.3). The upper portion of GLEES contains three small lakes located in glacial cirque basins: Lost Lake (6.7 ha, fig. 1.4), West Glacier Lake (3.3 ha, figs. 1.5–1.7), and East Glacier Lake (2.9 ha, figs. 1.6–1.8), with their corresponding watersheds of 51.4, 60.7, and 28.7 ha. Also included in GLEES are about 110 ha north of the East Glacier, West Glacier, and Lost Lakes watersheds on the Glacier Peak ridge; and 110 ha south of the three watersheds, north of Telephone Lakes and the road on the north side of Brooklyn Lake. An additional area of approximately 200 ha extends southeast of the East Glacier Lake watershed, east of the Brooklyn Lake road, to just east of Little Brooklyn Lake. This area includes subalpine forest not present in the upper GLEES. Only the upper GLEES area of East Glacier and West Glacier and Lost Lakes watersheds has been characterized for this report. Except for this introductory chapter, the material presented in this manuscript, unless otherwise noted, refers only to the East Glacier, West Glacier, and Lost Lake watersheds. This is where much of the research and monitoring is conducted. Additional information on the remaining areas of GLEES will be compiled later.

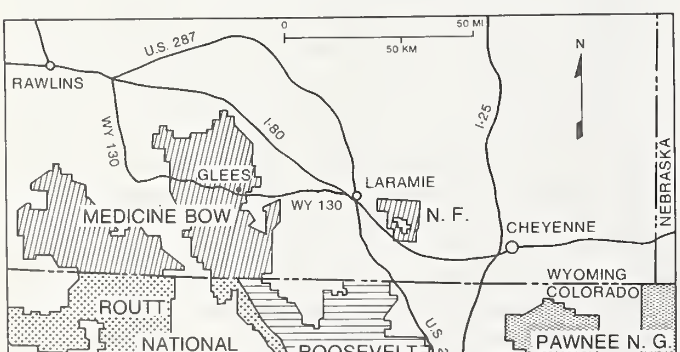


Figure 1.1.—General location of GLEES, in Medicine Bow National Forest, southeastern Wyoming.

East and West Glacier Lakes are located in the S 1/4 of Section 3, and Lost Lake is in the NW 1/4 of Section 9, T16N R79W, 6th P.M. The site is located on the Sand Lake, Centennial, Medicine Bow Peak, and Morgan Quadrangles, WY USGS 7 1/2 Minute Series Topographic Maps. The site is north and east of Brooklyn Lake, and it can be reached by driving north from State Highway 130 on the Forest Service Brooklyn Lake Road, FDR 317, which exits Highway 130 at the Mountain Meadows Resort (figs. 1.2, 1.3). A trailhead to the GLEES lakes is located at the north end of the Brooklyn Lake Campground.

Site Management and Access

GLEES is in the Laramie Ranger District of the Medicine Bow National Forest. Laramie Ranger District Headquarters is located at Laramie, Wyoming, but a Visitors Center located about 1.5 km NW of Centennial is open during the summer to provide information to Laramie District users. Current management of GLEES and the surrounding area is primarily for recreation use, with off-trail use of motorized vehicles restricted to snow machines. Primary summer use is for fishing and day hiking, but infrequent overnight camping is also evident. GLEES is in an area of the Laramie Ranger District that has been removed from mining claims; but the area still contains many active, though unworked, mining claims. Grazing has recently been removed in the upper portion of GLEES.

GLEES has no roads within the study area but is accessible from Forest Service Road FDR 317 on the southwest portion of the site in the summer. The site can be accessed by snowmobile in the winter and is about 5 km from the Highway 130 winter closure turnaround point at Green Rock Picnic Area (fig. 1.2). The south edge of East Glacier Lake is about a 15-minute hike from the Brooklyn Lake road at the Brooklyn Lake Campground, while Lost Lake is a 20-minute hike west of West Glacier Lake. A trail enters Lost Lake from the west, just northwest of the Lost Lake outlet, and is used primarily by fishermen and hikers. Numerous smaller trails exist within the site, but most site users are fishermen or hikers who confine themselves to the main trails or stay near the lake edges. Most visitors remain in the area of East and West Glacier Lakes. East and West Glacier Lakes are at lower elevations than Lost Lake and are the most easily accessible. Lost Lake is farthest from the road and is closest to the edge of the glacial cirque. Avalanche hazard inhibits access to both Lost Lake and West Glacier Lake in the winter.

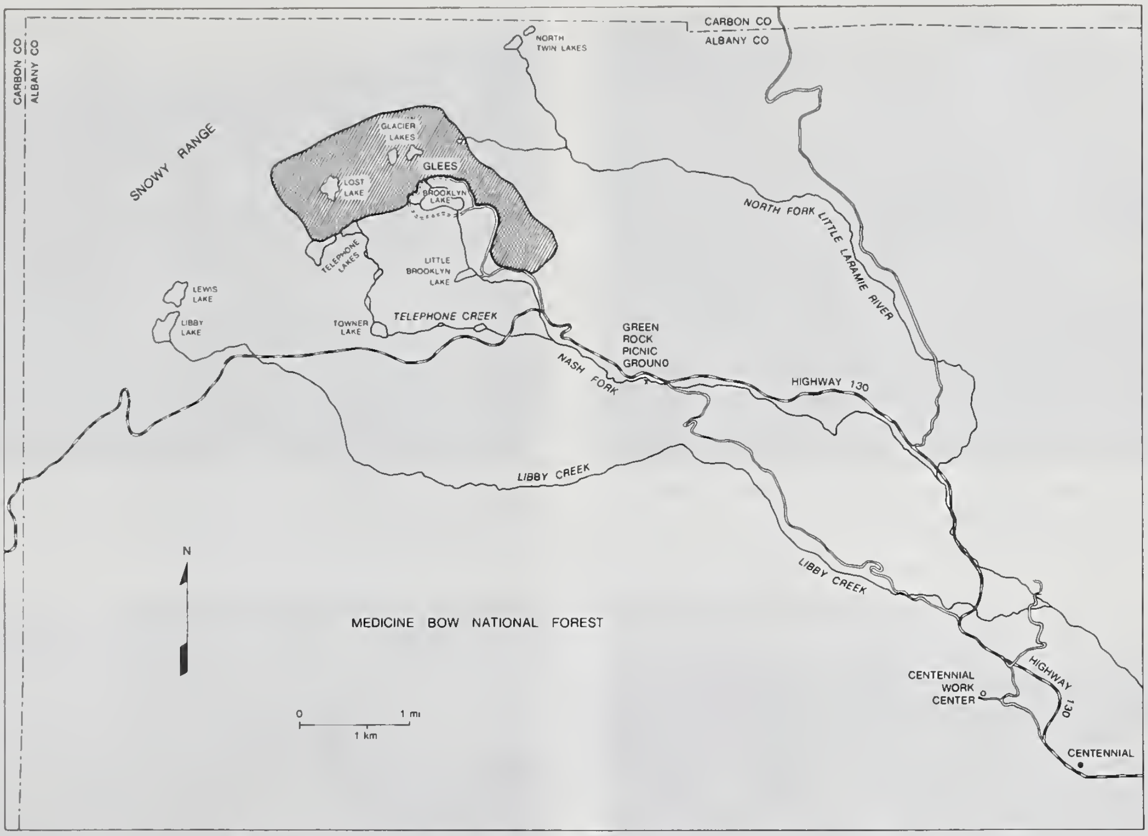


Figure 1.2.—Local area map of GLEES, showing location of Centennial, Centennial Work Center, Green Rock Picnic Ground (winter highway turnaround), and area lakes and streams.

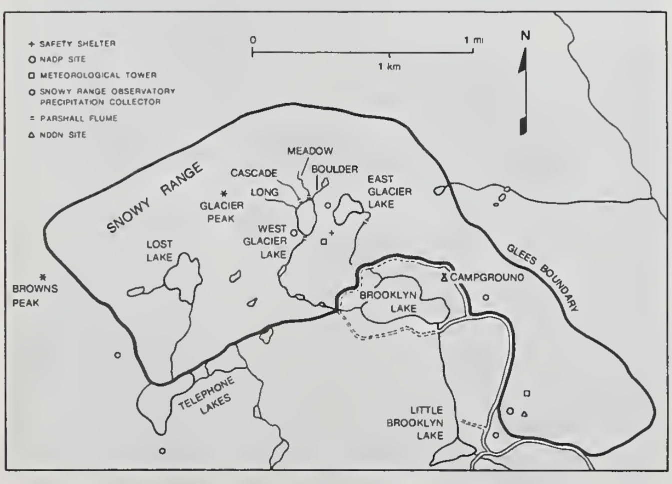


Figure 1.3.—Site location of research installations at GLEES. Inlet and outlet streams of the lakes are also shown.

Figure 1.4.—Lost Lake, taken from the south, near the outlet. Note the snowfields near the top of the cirque, and the avalanche debris at the base of the cirque at the north shore of the lake.

Figure 1.5.—West Glacier Lake, from the ridge between East and West Glacier Lakes, looking NW.

Figure 1.7.—West Glacier Lake (front) and East Glacier Lake (background), taken from the west of West Glacier Lake.

Figure 1.6.—West Glacier Lake (right) and East Glacier Lake (left) from the base of the snowfield feeding Meadow Creek. Meadow Creek is to the left of the tree-covered ridge running toward the lake in the lower center of the photo; Cascade Creek is to the right of that ridge. Long Creek enters West Glacier Lake from the right of the photo, through the scree field at the bottom right corner of the lake. Boulder Creek enters through the scree field at the lower left corner of West Glacier Lake. Brooklyn Lake can be seen above the right side of East Glacier Lake.

Figure 1.8.—East Glacier Lake from the eastern edge of the watershed. Note the snowfields at the top of the glacial cirque in the West Glacier Lake watershed. Melt from the smaller snowfield to the right flows into Meadow Creek. This snowfield melts out most years. Melt from the larger, permanent snowfield to the left flows into Cascade Creek.

Landscape Habitats

GLEES is in the subalpine forest/alpine ecotone. Vegetation at the site is characteristic alpine and subalpine taxa. Engelmann spruce and subalpine fir forests dominate at the lower portions of the site (fig. 1.9). These two species form krummholz stands at the higher elevations (fig. 1.10), where willows are also common in drainage or other wet areas. This area is also interspersed with meadow vegetation or cushion plants, depending upon soil development and moisture availability. The higher elevations become increasingly barren and have a covering of small cushion plants characteristic of alpine flora. A considerable portion of the watershed is not vegetated, consisting primarily of scree, rock outcrop, water, and/or snowfields. A description of 12 landscape habitats at the Lost, East Glacier, and West Glacier watersheds is presented in Chapter 2.

Vegetation

Plant communities at GLEES are distributed across a mosaic of habitat types that are influenced by complex, discontinuous stress gradients of wind distribution, snow cover duration, and microtopographic factors. The plant associations are separated by different species complexes and by dominant life forms. GLEES vegetation is characteristic of central and southern Rocky Mountain subalpine forests, subalpine wetlands, and alpine tundra. No endemics have been identified at

GLEES. The floristics of Lost Lake and East and West Glacier Lakes watersheds are described in Chapter 3. A herbarium collection of plant species at GLEES is maintained in cooperation with the University of Wyoming Rocky Mountain Herbarium in Laramie.

There have been vegetation disturbances at GLEES—primarily sheep grazing and recreational use by hikers, fishermen, and horses. Impact of these disturbances is considered minor. Most of the recreational use and impact is confined to the trails around the lakes, evidenced by compaction and sparseness of vegetation typical of trails. The alpine meadows surrounding GLEES have been used for permit sheep grazing since the late 1800's. In recent years, grazing at the immediate GLEES site has been infrequent and of short duration, primarily because of the sparse browse available and roughness of the terrain. Since 1990, grazing has been prohibited at the upper, steeper portions of the GLEES site. There are also numerous mining claims in the area, but the area has been recently withdrawn from new mining claims. Only three exotic species (dandelion, dark goosefoot, and many flowered woodrush) have been identified at GLEES, and abundance of these is very low. The small number of introduced species is perhaps due to the low impact of human activity at the site.

Figure 1.9.—Typical terrain and vegetation at GLEES. Note rocky nature of terrain and wind-deformed trees (*Abies lasiocarpa*).

Figure 1.10.—View of the permanent snowfield at the top of the glacial cirque at GLEES. Photo was taken at a location west of West Glacier Lake. Note the extensive area of exposed bedrock, wind-deformed trees in the center of the photo, and krummholz at the base of the snowfield.

Ninety permanent plots have been established in East and West Glacier Lakes watersheds for vegetation analyses. About 60 plots have been established in the lower GLEES area east of Brooklyn Lake. The vegetation of this general region of the Snowy Range, within 10 km of GLEES, has also been extensively studied by Billings and his colleagues (Billings and Bliss 1959) during the past 30 years. Many of the pioneering studies in alpine ecology and ecophysiology were conducted in the alpine areas of the Medicine Bow Mountains.

Geology and Soils

The major portion of GLEES is located on the steeply sloping SE-facing side of a SW to NE quartzite ridge whose main features are the Medicine Bow Peak and Browns Peak west of the study area (fig. 1.11). The site has developed from recent glaciation, with glacial cirque basins on the south side of the main ridge forming the upper reach of each of three watersheds. An alpine lake is the dominant feature of each watershed. A permanent snowfield exists at the top of the West Glacier Lake cirque. Bedrock at the site is primarily Medicine Bow Peak quartzite. Soils are minimally developed, formed over uniform quartzite bedrock that is crossed by weatherable mafic intrusions of amphibolite. Glacial till is present in the lower elevation areas of the watersheds. Exposed bedrock, talus slopes, or scree are evident in large areas of the site. More detail concerning geology at GLEES is presented in Chapter 4, and descriptive soils information is in Chapter 5.

Aquatics

The aquatic environment at GLEES is dominated by the snowpack and hydrological processes. Lakes have low buffering capacity and are impacted by a spring

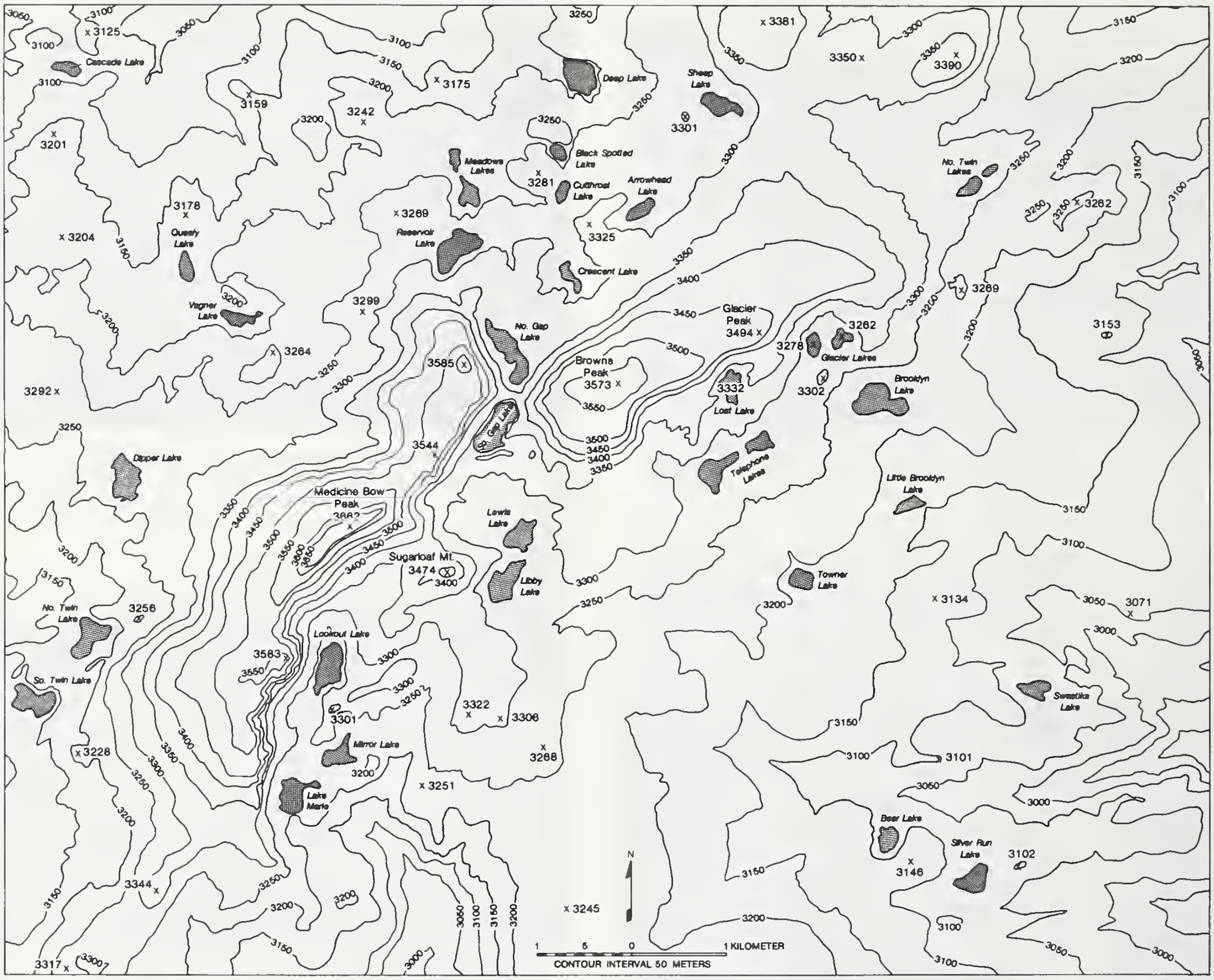


Figure 1.11.—Topographic map of GLEES and surrounding area, showing SW to NE Snowy Range Medicine Bow quartzite ridge, with upper GLEES (Lost Lake and Glacier Lakes watersheds) in glacial cirque basins south of the ridge.

acidic pulse at initial snowmelt. Input of this pulse is influenced by hydrological pathways into the lakes and streams. A preliminary examination of the physical, chemical, and biological aspects of the aquatic systems at GLEES is detailed in Chapter 6.

Meteorology and Air Quality

Long-term weather data have been collected near the site as a part of the Snowy Range Observatory operated by the Wyoming Water Research Center. Information from this database indicates mean minimum and maximum temperatures near the GLEES watershed ranging from lows of −23°C to highs of −1°C in winter, and lows of −7°C to highs of 21°C in summer. Precipitation is highly variable, with most in the form of snow. Snow cover frequently exists from late October until July. Measured precipitation averages 89 cm west of Lost Lake, 107 cm between East and West Glacier Lakes, and 125 cm near the East Glacier Lake outlet at Brooklyn Lake. Air quality data is collected as wet deposition, dry deposition, and ozone from the National Atmospheric Deposition Program (NADP) and National Dry Deposition Network (NDDN) monitoring sites at GLEES.

Wind speed and direction, air and soil temperature, solar radiation, and precipitation data have been collected since 1987 from a 15 m meteorological tower near West Glacier Lake and from a 30 m meteorological tower east of Little Brooklyn Lake. Wind speed, on exposed locations of the watershed, can average above 34 km/hr and is high year round. Winds are primarily westerly at the surface, with northerly winds coming over the ridge of the glacial cirque resulting in a large snow cornice above West Glacier Lake. These two wind patterns converge at the eastern edge of the East Glacier watershed. Mean maximum snow accumulation is about 2 m depth at GLEES. Annual precipitation is about 100 cm of H_2O. Summaries of preliminary data on meteorological conditions at GLEES are presented in Chapter 7, and initial information on air quality at GLEES is summarized in Chapter 8.

Topography and General Hydrology

GLEES is located at high elevation in steep, rocky terrain (fig. 1.12). A 2-meter resolution topographic map of the upper GLEES is presented in figure 1.13. The highest elevation in the site is 3494 m at the top of the NW to SW quartzite ridge. A ridge from this point runs south to divide the Lost Lake and West Glacier Lake watersheds, each having a glacial cirque at the top of the basin just south of the ridgetop. Lost Lake, at 3332 m elevation, is directly at the base of a well-defined, steep, unstable, cirque basin. A small pond, Scott Lake, at 3360 m on the west edge of the watershed near the top of the ridge drains into Lost Lake. A small drainage enters Lost Lake from the NE, fed from a snowfield that melts out in late summer. This drainage supports willow thickets near the lake, indicating moist soils. A small snowfield persists through the summer in some years on the talus slope above Lost Lake. A small, perched pond with no outflow after snowmelt is located on the ridge between

Figure 1.12.—Aerial photo of Lost Lake, East Glacier Lake, and West Glacier Lake watersheds, 1:4800 scale. Lost Lake is to the left, and West and East Glacier Lakes are on the right. The Medicine Bow Ridge with snowfields runs along the top of the photo (also shown in figure 1.11). Note the steep terrain and sparse vegetation. Aerial photo was taken August 19, 1988. (See Appendix F.)

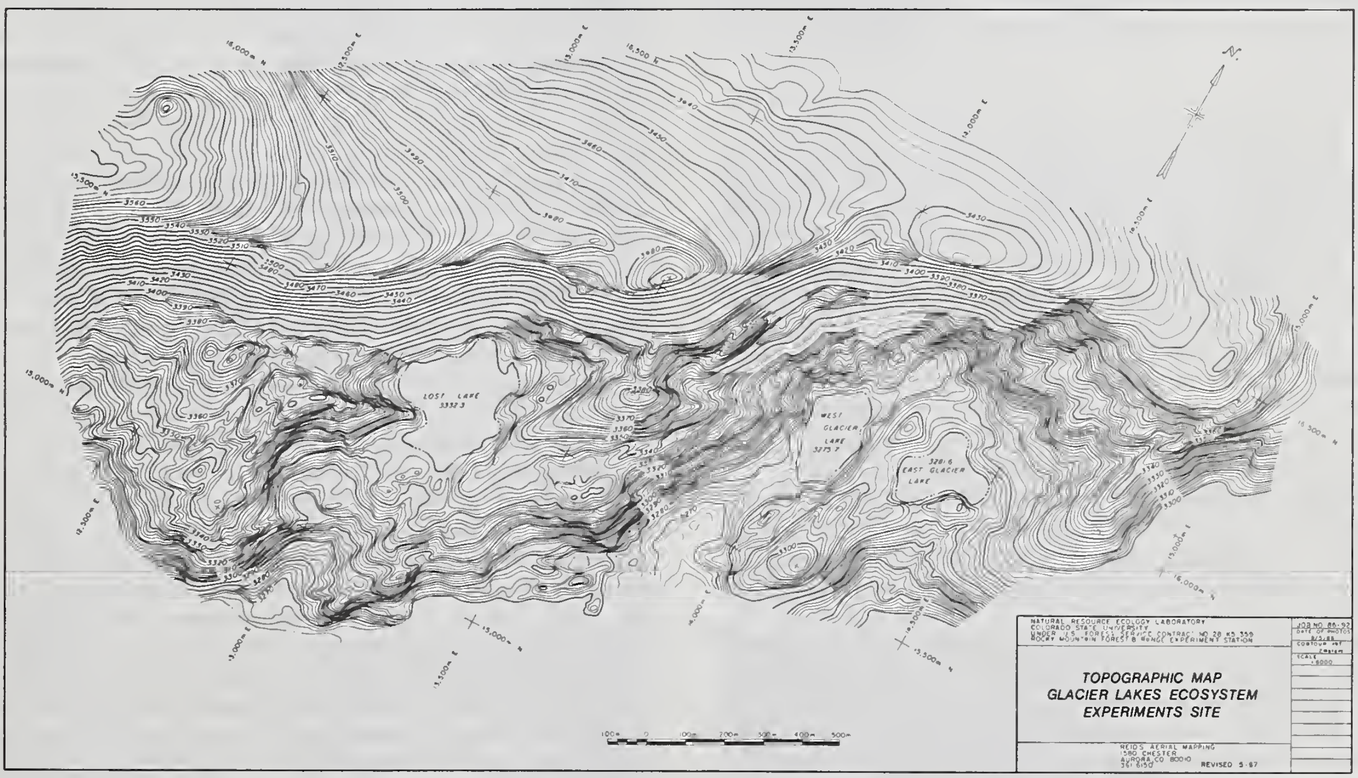


Figure 1.13.—Topographic map of GLEES, with 2-meter contour interval.

Lost and West Glacier Lakes watersheds. This pond has no fish and supports a rare crustacean, the fairy shrimp *Brachinecta paludosa*. Another small, shallow pond is located SE of the East Glacier Lake watershed. The lower portion of GLEES is on a relatively flat NW to SE ridge and contains deeper soils supporting spruce/fir forest.

East and West Glacier Lakes (figs. 1.6, 1.7) are similar in size, depth, and elevation. East Glacier Lake is slightly farther from the base of the steep portion of the quartzite ridge. East Glacier Lake, at 3282 m elevation, is 100–150 m east of West Glacier Lake, at 3276 m elevation. A low, windswept ridge running north to south separates the two watersheds. Four well-defined snowmelt drainages flow into the north end of West Glacier Lake (figs. 1.3, 1.5). Boulder Creek flows NE to SW from two drainage basins that merge to form a shallow pond, Boulder Pond, at the NE corner of West Glacier Lake. The pond outlet flows through scree about 100 m before entering the NE corner of West Glacier Lake. Cascade Creek and Meadow Creek are fed from the permanent snowfield (fig. 1.10) in a glacial cirque at the top of the watershed; however, only a small amount of Meadow Creek flow comes from the permanent snowfield late in the melt season. Smaller snowfields feeding Meadow Creek melt out most years. Meadow Creek enters the north side of West Glacier Lake (east of Cascade Creek) after flowing through a wet meadow. Cascade Creek feeds through a steep, rocky drainage channel to enter the north side of West Glacier Lake. Long Creek flows through rocky areas NW of West Glacier Lake, but it enters scree and becomes undefined about 100 m from the lake shore. Long Creek is fed by a snowfield that melts out most years by late summer. West Glacier Lake outlet stream drains to the SW through scree, wet meadow, and willow thickets. Several small ponds are located along the outlet.

East Glacier Lake has no perennial streams, and many intermittent streams are not well-defined. Almost all of the East Glacier Lake drainage basin lies to the east of the lake. Much of the East Glacier inlet area consists of wet meadow and springs near the lake. At the upper reaches of the watershed, snowmelt channels into NE- to SW-flowing drainage basins that become undefined as they reach the lake. Large areas of wet meadow and willow thicket on the east edge of East Glacier Lake indicate areas of moist soil, suggesting surface and subsurface flow into the lake in the absence of defined streambeds. Large areas of surface flow are evident in this area during snowmelt. There are no permanent snowfields in the East Glacier Lake watershed, and flow into the lake stops soon after snowmelt. East Glacier outlet initially flows east through scree from the southeast corner of the lake. The stream emerges in a well-defined channel about 200 m from the outlet. Outflow ceases in late summer.

Overall, there is a large diversity of types of streams at GLEES, including well-defined rocky streambeds, well-channelized streambeds through meadows, and poorly defined streambeds through rocky terrain or through meadows. All three GLEES lakes have extremely low acid neutralizing capacity. The hydrology of GLEES is extremely complex because of the irregular topography, the large amount of unconsolidated surface materials and fractured nature of the bedrock, the variability of channelized flow to the lakes, and the relatively undeveloped soils. Chapter 9 presents an initial estimate of hydrologic flows at GLEES.

Snow

A major portion of precipitation at GLEES is in the form of snow. Snow cover generally persists at the site from November through June, with some snow patches persisting into August or September. A permanent snowfield supplies meltwater to West Glacier Lake until winter freeze. Snowmelt at GLEES dominates stream and lake chemistry except where water flows through mafic areas or meadows. Snow input to GLEES is examined in Chapter 10.

Research Installations and Programs

Long-term databases and research installations used to collect the data are listed in table 1.1. Major research facilities installed at GLEES include Parshall flumes on four streams, a wet deposition collector and associated Belfort rain gage, a dry deposition collector, a 15 m meteorological tower, a 30 m meteorological tower, a Wyoming Shielded Belfort precipitation collector, and a safety shelter (fig. 1.3).

East and West Glacier Lakes have been gaged with Parshall flumes on their outlets. Two inlet streams on West Glacier Lake (Meadow and Cascade Creeks) have also been gaged. Flow from Cascade Creek, fed from the permanent snowfield, and flow from the West Glacier Lake outlet continue until winter, and resume at snowmelt in the spring. Long Creek, Boulder Creek, and the East Glacier outlet maintain flow from initial snowmelt until soon after the snowfields are gone. Meadow Creek is fed from the permanent snowfield early in the season, but slows to a trickle as the snowfield recedes in late summer and fall. The East Glacier outlet Parshall flume is located at the end of the scree field about 100 m from the SE corner of the lake. The West Glacier inlet and outlet Parshall flumes are at the lake shore.

Meteorological data have been collected near GLEES since the late 1960's as a part of the Snowy Range Observatory (SRO) network, operated by the University of Wyoming. As a part of this network, in 1976 a precipitation collector with a Wyoming Rain Shield was installed on the ridge between East and West Glacier Lakes. In 1987, a solar-powered 10 m meteorological tower was installed on a knoll about 100 m SE of West Glacier Lake (fig. 1.14). Temperature, relative humidity, wind speed and direction, precipitation, wetness duration, soil temperature, and solar radiation are recorded at this site. An NADP wet precipitation collector is located near the SW shore of West Glacier Lake. A 30 m meteorological tower with 220V power is located east of Little Brooklyn Lake. Temperature, humidity, wind speed and di-

Table 1.1.—Long-term databases at GLEES and associated research installation sites.

Location	Measurements
Meteorological data	
Meteorological towers	Wind speed, wind direction, relative humidity, air temperature, soil temperature, precipitation, pyranometer radiation
NADP site	Precipitation, snow, radiation, pan evaporation, wind speed, wind direction (Jun - Oct), snow depth, snow temp, snow wetness (Nov - Jun)
SRO site	Precipitation
Air quality data	
NDDN site	Ozone, dry deposition chemistry
NADP site	Wet deposition chemistry
Hydrological data	
Lysimeters	Snow, soil chemistry
Lakes and streams	Flow, water chemistry—East Glacier Lake outlet, West Glacier Lake outlet, Meadow Creek, Cascade Creek Water chemistry—East Glacier Lake, West Glacier Lake, Lost Lake, Scott Creek, Scott Lake, Boulder Creek, Long Creek, pond between Lost Lake and West Glacier Lake
Snowcore survey	Depth, density, chemistry (East & West Glacier Lake watersheds)
Snowpits	Chemistry, depth, layering
Biological data	
Vegetation	Permanent plots
	Abundance data for all vascular flora
	Checklist of vascular plants
	Collection of voucher specimens for all vascular flora
Aquatics	Phytoplankton, zooplankton, periphyton Checklist of phytoplankton

Figure 1.14.—Meteorological tower at GLEES, located SW of East Glacier Lake.

rection, solar radiation, particulate concentration, sulfur and nitrogen species concentration, and ozone concentrations are recorded at the Brooklyn tower site.

A NADP wet deposition collector, established in 1986, is located on the SW shore of West Glacier Lake for measurement of wet deposition. Information from this site is available from the NADP network database. A NDDN station was established in February 1989 near the Medicine Bow National Forest Centennial Ranger District Work Center. The NDDN station is part of a network of dry deposition monitoring stations established by the U.S. Environmental Protection Agency. The NDDN station was moved to the Little Brooklyn Lake meteorological tower site in 1990. Ozone and dry deposition information from this site is available from the NDDN network database.

There are no laboratory or boarding facilities at GLEES, but the site is less than a 1-hour drive from Laramie. Limited motel space is available at Centennial, or with advanced arrangement at resorts within 3 km from the site. A National Forest campground is located at the NW corner of Brooklyn Lake directly adjacent to the GLEES. The Rocky Mountain Forest and Range Experiment Station has established a field laboratory and provides limited housing for their staff and research cooperators at the Centennial Ranger District Work Center less that 20 km from the site. Since weather conditions can change rapidly in the area, a temporary emergency shelter is located SW of East Glacier Lake for use by researchers who might be caught in the watershed during inclement weather, or for those in need of emergency first aid equipment.

Research at GLEES is coordinated by a GLEES Research Committee, chaired by a scientist from the Rocky Mountain Forest and Range Experiment Station, and includes scientists from the University of Wyoming and the Medicine Bow National Forest. Research proposals are evaluated by the GLEES Research Committee for scientific merit and for conflicts with area use or other research. Operational aspects of research approved by the Medicine Bow National Forest are coordinated by the Rocky Mountain Forest and Range Experiment Station, Research Work Unit 4452, located at station headquarters in Fort Collins, Colorado.

Measurements of magnitude of input of wet and dry deposition of cations and anions are being made at GLEES. All GLEES meteorological, biogeochemical, and vegetation data are archived in a PARADOX database at the Rocky Mountain Station. In addition to establishing a database on atmospheric deposition in sensitive alpine ecosystems, field studies will be conducted in controlled experiments to measure terrestrial and aquatic response to physical and chemical changes in the atmosphere.

Summary

This document provides a description of the upper GLEES study area and preliminary data on the biological, physical, and chemical environment at the site. Initial descriptions of vegetation, geology, soils, aquatics, meteorology, air quality, and snow for the Lost Lake, East Glacier Lake, and West Glacier Lake watersheds are presented. Detailed checklists of plant species (appendices A and B), macroinvertebrates (appendix C), and soil descriptions (appendices D and E) for these areas are also included. Baseline grid orthophotographs for precise research site location in winter and summer are provided (appendix F). Detailed topographic, vegetation, geology, and soils maps are included in the appropriate chapters.

Reference

Billings, W.D.; Bliss, L.C. 1959. An alpine snowbank environment and its effects on vegetation, plant development, and productivity. Ecology. 40(3): 388–397.

2. LANDSCAPE HABITATS

C.L. Simmons
Natural Resource Ecology Laboratory
Colorado State University, Fort Collins, Colorado

This landscape habitat description is based on a ground reconnaissance of the Lost Lake, West Glacier Lake, and East Glacier Lake portions of GLEES conducted during 10 days in July-September 1986 and on subsequent photo interpretation of 1:6000 scale color-infrared photographs. A ground check was conducted in July-August 1987. The classification used is a physiognomic classification of vegetation/landscape types in the study area. As such, it is based on the structural, rather than floristic, characteristics of the vegetation. Preliminary information on the floristic composition of the vegetation was obtained in the initial field reconnaissance. A detailed floristics description is presented in Chapter 3.

Methods

The ground reconnaissance located areas of apparent homogeneity on the aerial photographs, noted the physiognomic character of the vegetation as well as the amount of rock and vegetative cover, and listed the predominant vascular plant taxa present. No effort was made in the initial habitat classification to conduct a comprehensive survey of the taxa present in the study area, to characterize plant communities or associations, or to list all taxa in a given location. Such information is useful for studies of ecosystem processes and was gathered after the initial vegetation/landscape physiognomic classification and mapping (see Chapter 3). A second goal of the initial ground reconnaissance was to determine whether alpine species were present in the watersheds; therefore, particular attention was paid to areas with herbaceous vegetation where alpine taxa were deemed likely to occur.

The information obtained from the ground reconnaissance was used for the subsequent interpretation of 1:6000 color-infrared aerial photographs. Twelve vegetation/landscape types were recognized (table 2.1). For mapping purposes, two of these vegetation types, krummholz conifer and coniferous forest, were subdivided based upon percent cover. Two other vegetation types (willow shrub outside of wet meadows, and tall forb wet meadow) occurred rarely within these watersheds and were not mapped independently. The photographs were viewed in stereo, and map units were delimited on the photographs on the basis of ground information, the spectral appearance of the unit, and the topographic position of the unit relative to the general landscape. The unit boundaries were then transferred to a 1:6000 scale topographic base map with the assistance of a zoom transferscope. To correct for photographic distortion, care was taken during the transfer to align distinctive topographic features and relate control points on the photographs to those on the base map. Despite this effort, some inaccuracies likely exist, particularly in the locations of unit boundaries on the steep cirque walls in the NW portion of the map where the photographic images were most distorted.

Table 2.1.—Vegetation/landscape types in the Lost Lake, West Glacier Lake, and East Glacier Lake watersheds. Vegetation/landscape type areas differ from calculated watershed areas (Chapter 1) since the vegetation survey extended beyond watershed boundaries.

Vegetation/landscape type	Area (ha)
1. Meadow	40.4
2. Krummholz conifer	36.9
3. Coniferous forest	30.5
4. Cushion plants/stone pavement	11.9
5. Wet meadow/willow shrub	9.4
6. Scree/meadow	6.2
7. Willow shrub	1.1
8. Tall forb wet meadow	0.7
9. Scree	22.7
10. Rock outcrop	16.5
11. Water	13.0
12. Snowfield	9.4
Total area	198.7

The areal extent of each vegetation/landscape type was estimated by cutting and weighing the units from the completed map. This method is similar to a planimetric measurement in that it tends to underestimate the area of inclined surfaces. These areas are primarily the krummholz conifer, scree, rock outcrop, and snowfield areas near the top of the map.

Vegetation/Landscape Descriptions

Twelve vegetation/landscape types are listed in table 2.1 with the estimated areal extent of each type in the study area. The vegetation map is presented in figure 2.1.

One hundred twenty-three vascular plant taxa were identified in the study area in the initial reconnaissance. Of these taxa, 100 have also been reported for the Indian Peaks alpine area in Colorado (Komarkova 1979). According to Komarkova (1979), 37 of the 100 taxa are primarily montane or boreal-montane in their geographic distribution, 17 are arctic-alpine, and the remaining 46 are primarily alpine. In the study area, the alpine and arctic-alpine taxa occur primarily in the

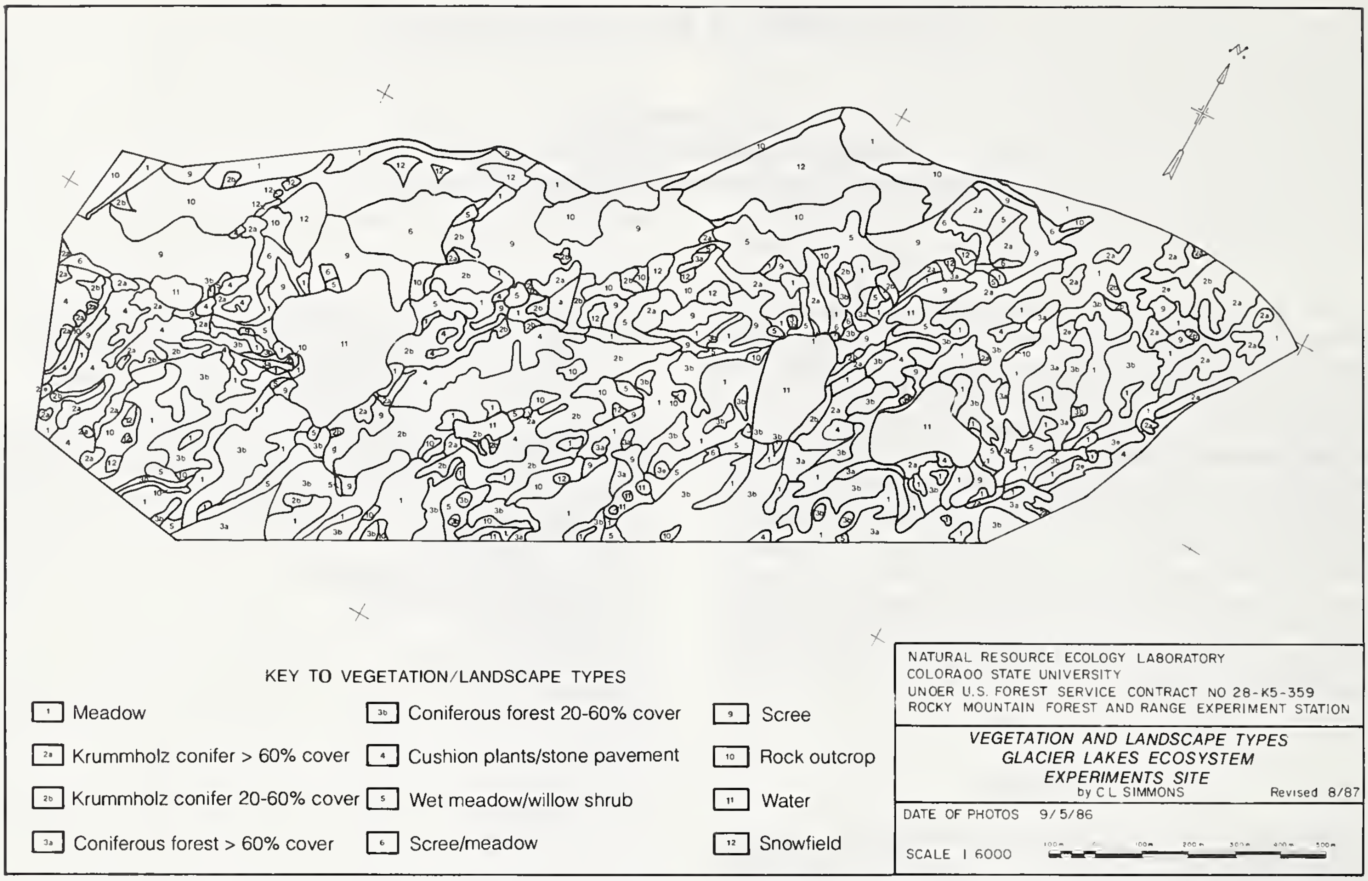


Figure 2.1.—Vegetation/landscape types map of the GLEES. Vegetation types 7 (willow shrub) and 8 (tall forb wet meadow) are included with vegetation type 5.

meadow and cushion plant vegetation/landscape types. It should be noted that this initial species checklist for the study area represented only 10 days of field observation. However, it identified a large number of alpine and arctic-alpine taxa in the study area.

A large part of the study area (34%) supports coniferous vegetation (coniferous forest and krummholz conifer). Herbaceous vegetation types (meadows, cushion plant-dominated ridge tops, and partially vegetated scree) comprise 30% of the study area, and willow shrub types (willow shrub and wet meadow/willow shrub) comprise an additional 5%. The remainder of the study area is largely unvegetated, consisting of rock outcrop (8%), scree (11%), snowfield (5%), and water (7%). Although the rock outcrops and scree are only sparsely vegetated, other workers have described plant associations specific to these habitats (e.g., Komarkova 1979). The 12 vegetation/landscape types are described below. The common plant names used in the text are identified by botanical names in Appendix A.

Meadow

The vegetation included in this category is highly diverse. The floristic composition varies greatly over short distances (meters or less), depending on a variety of factors including moisture, duration of snow cover, and degree of animal disturbance (Billings and Bliss 1959, Komarkova 1979). The term *meadow* is used here in a broad sense to describe a wide range of herbaceous plant communities including grass-sedge turf, tallgrass, late-lying snowpatch, and dry- and moist-meadow subtypes. Areas mapped as meadow may also support scattered trees, willows, or krummholz conifers, but the cover of these woody plants is less than 20%.

Krummholz Conifer

With increasing elevation and exposure to wind, trees in the watershed assume a deformed or "krummholz" form. Spruce and fir layer at the base, often forming dense mats. Limber pine does not layer, but assumes a prostrate form in response to the wind. Matlike stands have little or no understory, but more open stands often contain the understory species listed for the coniferous forest. Willows, particularly shortfruited willow, are frequently associated with the krummholz conifers; common juniper is often present as well. At the top of the watershed above East Glacier Lake, shortfruited willow is abundant on the leeside of the krummholz conifers. The krummholz conifer type is divided into two estimated cover classes. Openings in the lower cover

class are in many cases occupied by rock or scree, but they may also contain meadow or cushion plant vegetation. At the low end of the range of canopy cover, this type grades into rock outcrop, cushion plant, scree, or meadow types.

Coniferous Forest

Coniferous forest occurs primarily at lower elevations in the watershed and in more protected sites at intermediate elevations. At higher elevations and on more exposed ridges the same conifer species occur in wind-deformed or krummholz form (see above). The forest consists primarily of Engelmann spruce and subalpine fir with occasional limber pine. Stands are generally narrow and discontinuous, in some areas forming "ribbons" of forest with meadow in between. Many of the trees are "flagged" or entirely devoid of branches on their upper trunks from wind desiccation or snow abrasion. Important understory taxa include broom huckleberry, currants, bracted lousewort, sickletop lousewort, and hairycap moss (*Polytrichum* sp.), as well as scattered bluegrasses and sedges. Snow duration is an important regulator of understory composition. Knight and co-workers (1975) found that broom huckleberry, the predominant understory species, was intolerant of snow cover past the first week in July. The two forest classes shown on the map are separated on the basis of estimated canopy cover. The taxa listed occur in both canopy classes. The more open forest usually has more herbaceous cover and may have large amounts of hairycap moss, broom huckleberry, bearberry, arnica, subalpine daisy, and dwarf bilberry in the openings. At the low end of the range of canopy cover (approximately 20%) the open forest grades into the meadow type.

Cushion Plants/Stone Pavement

Rocky ridgetops that are presumably blown free of snow in winter support cushion plant vegetation. There is little soil visible on the surface and a lag surface of gravel. The plants mostly have a cushion form, although junipers, bearberry, and willows may establish on the leeside of boulders and in depressions. Patches of dry meadow vegetation generally occur in more protected sites within these units. The vegetation in this type is very diverse and varies over short distances. Common species include rock selaginella, sandworts, creeping sibbaldia, whiproot clover, moss campion, thickleaved candytuft, Parry lousewort, alpine bistort, cushion phlox, curly sedge, and bentgrasses. Lichens and mosses are also major components of this vegetation type. This type grades into meadow, open krummholz conifer, and rock outcrop types.

Wet Meadow/Willow Shrub

In the study area, large patches of willow occur primarily in drainages where they are associated with tall forb wet meadows and sedge meadow vegetation. This type is found in most of the major drainages entering the lakes and along the outlet streams of Lost Lake and West Glacier Lake. Shortfruited willow and plane-leaved willow are the predominant willow species. The herbaceous taxa are those listed below for tall forb wet meadows.

Scree/Meadow

Areas with well-stabilized scree support larger patches of meadow vegetation and grade into the meadow type. Areas mapped as scree appear unvegetated from a distance, while areas mapped as scree/meadow have 20–60% of their surface covered by herbaceous vegetation types. Meadows with large amounts of scree on the surface are similar in general appearance to the scree/meadow type but are more stabilized and generally occur on more gentle slopes.

Willow Shrub

In a few areas, patches of willows occur with little or no wet meadow vegetation. These areas are primarily on the steep faces of the cirque headwalls along snowmelt drainages. Krummholz conifer and common juniper are often associated with the willow thickets on the cirque walls. In the single example of this type that was visited, shortfruited willow was the main willow species. The extent of this type may have been overestimated, particularly for the steeper slopes, because the taller willows may have obscured the tall forbs on the aerial photographs. Scattered patches of willow shrubs, usually of low stature, may also occur sporadically in the other vegetation/landscape types, particularly the meadow, krummholz conifer, rock outcrop, and scree types.

Tall Forb Wet Meadow

Tall forb wet meadows occur primarily with willow thickets along streams and snowmelt drainages; however, they also occur along streams and in seeps where willows are locally absent. Common taxa include arrowleaf groundsel, mountain bluebell, brook saxifrage, bluejoint, rosecrown, elk marshmarigold, American globeflower, Holm's Rocky Mountain sedge, Drummond rush, small-flowered woodrush, and American alpine speedwell. This type grades into the meadow and wet meadow/willow shrub types.

Scree

Scree generally forms steep slopes at the bases of the cirque headwalls in the study area. Many of these scree slopes hold patches of snow well into the summer. A few fairly level scree units occur on the edges of the lakes. The scree supports small, widely scattered patches of vegetation in areas where soil has formed in its interstices. The vegetation varies greatly from patch to patch, but is predominantly herbaceous.

Rock Outcrop

Rock outcrops occur primarily along the upper parts of the cirque headwalls and on the ridge dividing Lost Lake and West Glacier Lake. The generally vertical rock faces support little vascular vegetation; however, patches of krummholz conifer, willow, and meadow vegetation occur in crevices and on benches. The units mapped as rock outcrop may include scree, meadow, and krummholz components that are too small to map individually; however, rock outcrops predominate.

Water

This landscape type includes the area occupied by East Glacier, West Glacier, and Lost Lake surfaces. The water level in the smaller ponds fluctuates seasonally. The area of these smaller ponds and streams were not included in this landscape type.

Snowfield

The areas mapped as snow were snow-covered on the September 5, 1986, aerial photographs. The largest snowfield is permanent, but the smaller snowpatches melt out in most years.

References

Billings, W.D.; Bliss, L.C. 1959. An alpine snowbank environment and its effects on vegetation, plant development, and productivity. Ecology. 40(3): 388–397.

Knight, D.M.; Kyte, C.; Rogers, B.; Starr, C.R. 1975. The impact of snow on herbaceous and shrubby vegetation. In: Final Report: The Medicine Bow Ecology Project. Laramie, WY: University of Wyoming Press: 175–214.

Komarkova, V. 1979. Alpine vegetation of the Indian Peaks Area. Vaduz, Germany: J. Cramer. 591 p.

245

3. FLORISTICS

J.D. Haines, R.C. Musselman, and C.M. Regan
Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado

The initial habitat classification as described in Chapter 2 was conducted in 1986 and 1987 based upon field identification of plant species. A field collection of vascular plant species was made during the 1988, 1989, and 1990 summer seasons. The plant species collected were identified and verified in cooperation with the Rocky Mountain Herbarium at the University of Wyoming. Voucher specimens are archived at the Herbarium. A complete set of voucher specimens (one or more for every terrestrial taxon) is also located at the Rocky Mountain Station's Centennial laboratory for use during the field season. A total of 209 vascular plant species (and 213 vascular plant taxa) were collected and identified in 1988, 1989, and 1990 in the higher elevation area of the GLEES (Lost Lake, West Glacier Lake, and East Glacier Lake watersheds). Only 17 taxa initially field identified in the 1986 and 1987 reconnaissance were not collected in 1988, 1989, and 1990.

The life cycle of many of the plant species at the GLEES is short, with growth, flowering, seed set, seed maturation, seed dissemination, and senescence occurring within a few weeks. This strategy allows these species to reproduce and perpetuate themselves in the alpine and subalpine habitats typical of the GLEES, with the short growing season between spring or early summer snowmelt and the first killing frost in the fall. The entire vegetative and reproductive life cycle may be completed within days. Period of flowering may be only a few days or hours in some species in some habitats. Thus, it is expected that additional vascular plant species occur at the GLEES which have not yet been collected and identified.

Only vascular plants from the higher elevation watersheds of the GLEES are currently included in the collections. Ferns have been identified at the GLEES, but their occurrence is uncommon. Some nonvascular plant species have been field identified, but these have not been systematically collected and verified. A large number of lichen species exists at GLEES. Their occurrence is scattered, with numerous species present in some habitats, and fewer in others. They appear to be particularly numerous on the eastern edge of GLEES. Mosses are prevalent in most habitats at the GLEES.

Floristically, the GLEES is characteristic of other subalpine and alpine sites found in the southern Rocky Mountains. Of the plant species collected and verified at the higher elevations of GLEES in 1988, 1989, and 1990, 25.4% are alpine, 13.6% are arctic-alpine, and 22.5% are boreal-montane according to their phytogeographic distribution (table 3.1). Primary references for phytogeographic distributions of these taxa include Rydberg (1914a, 1916, 1919), Great Plains Flora Association (1977, 1986), Harrington (1964), Hitchcock et al. (1955, 1959, 1961, 1964, 1969), Hulten and Fries (1986a,b,c), Komarkova (1979), Martin and Hutchins (1980, 1981), Weber (1967, 1987, 1990), and Welsh et al. (1987). The large number of alpine or arctic-alpine plant species occurring at the GLEES verifies that the area is typical of an alpine environment. These species are tolerant of the harsh environment characteristic of this area, and have a competitive advantage over less tolerant species.

Table 3.1.—Summary of the phytogeographic distributions of the vascular plant taxa of GLEES.

Geographic distribution	Number of taxa	Percent of total flora
Alpine	54	25.4
Arctic-alpine	29	13.6
Boreal-montane	48	22.5
Great Plains	2	0.9
Montane	76	35.7
Ubiquitous	4	1.9
Total	213	100.0

The 209 vascular plant species (213 vascular plant taxa) that were collected and verified in 1988, 1989, and 1990 are distributed in 36 plant families (table 3.2). The four families having the most species at GLEES were Asteraceae with 36 species (36 taxa), followed by Poaceae with 28 species (29 taxa), Cyperaceae with 19 species (19 taxa), and Caryophyllaceae with 14 species (15 taxa). Ten plant families were represented by only one species (one taxon), and two families had only two species (two taxa). Flowering plants comprised 95% of the vascular plant flora of the GLEES (table 3.3). Dicots, encompassing 67% of the vascular plant flora, were the largest major division of the vascular plant taxa present at the GLEES. Monocots comprised 28% of the vascular plant taxa. Only 3% of the vascular plant flora was made up of pteridophytes. The conifers represented the remaining 2% of the GLEES flora.

Only three introduced species have been identified to date at GLEES. They are *Taraxacum officinale* Weber (common dandelion), *Chenopodium atrovirens* Rydb. (dark goosefoot), and *Luzula multiflora* (Retz.) Lej. (many flowered woodrush). None of these three were prevalent at GLEES. The following plant species collected at GLEES are considered poisonous:

Juniperus communis L. var. *depressa* Pursh (common juniper, dwarf juniper)

Picea engelmannii Parry ex Engelm. (Engelmann spruce)

Table 3.2.—The composition of the vascular plant families of GLEES with respect to genera, species, and subspecific taxa.

Family	Number of genera	Number of species	Number of taxa
Asteraceae	14	36	36
Poaceae	10	28	29
Cyperaceae	2	19	19
Caryophyllaceae	7	14	15
Scrophulariaceae	5	9	9
Brassicaceae	4	8	8
Onagraceae	2	8	9
Juncaceae	2	7	7
Ranunculaceae	5	6	6
Rosaceae	3	6	6
Saxifragaceae	4	6	6
Ericaceae	4	5	6
Gentianaceae	4	5	5
Salicaceae	2	5	5
Pinaceae	3	4	4
Polemoniaceae	2	4	4
Polygonaceae	3	4	4
Polypodiaceae	3	3	3
Apiaceae	3	3	3
Boraginaceae	2	3	3
Fabaceae	2	3	3
Liliaceae	3	3	3
Portulacaceae	2	3	3
Violaceae	1	3	3
Crassulaceae	1	2	2
Primulaceae	2	2	2
Isoetaceae	1	1	1
Ophioglossaceae	1	1	1
Selaginellaceae	1	1	1
Cupressaceae	1	1	1
Callitrichaceae	1	1	1
Caprifoliaceae	1	1	1
Chenopodiaceae	1	1	1
Grossulariaceae	1	1	1
Hydrophyllaceae	1	1	1
Orchidaceae	1	1	1
(36 families)	105	209	213

Pinus contorta Dougl. ex Loud. var. *latifolia* Engelm. ex Wats. (lodgepole pine)

Pinus flexilis James (limber pine)

Conioselinum scopulorum (Gray) Coult. & Rose (hemlock parsley)

Sambucus racemosa L. ssp. *pubens* (Michx.) House var. *microbotrys* (Rydb.) Kearn. & Peeb. (scarlet elderberry, red elderberry, Rocky Mountain red elder, mountain red elderberry, red-berried elder)

Arctostaphylos uva-ursi (L.) Spreng. ssp. *uva-ursi* var. *uva-ursi* (common bearberry, kinnikinnick, sandberry, mealberry)

Arctostaphylos uva-ursi (L.) Spreng. ssp. *uva-ursi* var. *stipitata* (Packer & Denford) Dorn (bearberry, kinnikinnick, bearberry manzanita, sandberry)

Kalmia microphylla (Hook.) Heller var. *microphylla* (alpine laurel, alpine bog Kalmia, swamp laurel)

Lupinus argenteus Pursh var. *argenteus* (silvery lupine)

Zigadenus elegans Pursh (mountain death camas)

Anemone patens L. var. *multifida* Pritz. (pasque flower, wild crocus, Easter flower)

Juniperus, *Picea*, *Pinus*, *Arctostaphylos*, and *Kalmia* species are generally unpalatable and, consequently, toxic quantities of them are rarely ingested.

Twelve additional taxa have been found at the GLEES that were not in Burrell E. Nelson's 1984 *Vascular Plants of the Medicine Bow Range*. They are:

Carex bipartita All. (two-parted sedge)

Luzula multiflora (Ehrh.) Lej. (many flowered woodrush, hairy woodrush)

Poa secunda Presl var. *incurva* (Scribn. & Williams ex Scribn.) Beetle (curly bluegrass)

Antennaria rosea Greene (rose pussytoes, rosey pussytoes, pink pussytoes, pink everlasting)

Table 3.3.—Composition of the vascular plant flora of GLEES by major plant groups.

Groups	Families	Genera	Species		Subspecific taxa	
			Number	% of flora	Number	% of flora
Pteridophyta (club mosses, quillworts,horsetails or scouring rushes, and ferns)	4	6	6	2.9	6	2.8
Pinophyta (conifers)	2	4	5	2.4	5	2.3
Magnoliophyta (flowering plants)	30	95	198	94.7	202	94.8
Liliatae (monocotyledons)	5	18	58	27.8	59	27.7
Magnoliatae (dicotyledons)	25	77	140	67.0	143	67.1
Total	36	105	209	100.0	213	99.9

The two varieties of *Arctostaphylos uva-ursi* (L.) Spreng. ssp. *uva-ursi*, var. *uva-ursi* (common bearberry, kinnikinnick, sandberry, mealberry) and var. *stipitata* (Packer & Denford) Dorn (bearberry, kinnikinnick, bearberry manzanita, sandberry)

Epilobium angustifolium L. var. *angustifolium* (fireweed, common fireweed, fireweed willowherb, giant willowherb, blooming Sally)

Epilobium clavatum Trel. (alpine willowherb)

Epilobium lactiflorum Hausskn. (pale willowherb)

Gayophytum decipiens Lewis & Szweyk. (bigflower groundsmoke, spreading groundsmoke)

Polemonium brandegei (Gray) Greene (Brandegee sky pilot, Brandegee Jacobsladder, honey sky pilot, pale sky pilot)

Lewisia triphylla (Wats.) Robins. (threeleaf Lewisia).

It is evident from this large number of additional taxa, obtained during three field seasons of minimal collection, that the flora of GLEES (as well as that of the Medicine Bow Mountains, in general), is incomplete. At least five additional taxa were collected at the higher elevation areas of the GLEES site in 1991. A substantial number of new taxa should be expected in future seasons of work.

Three plant species outside their known range of occurrence have been identified at GLEES. These species were verified by taxonomists at the University of Wyoming Herbarium and can be considered uncommon for this area. *Antennaria aromatica* Evert was collected at GLEES in 1989 and was previously known in Wyoming only from Park County in NW Wyoming. *Lewisia triphylla* (Wats.) Robins. was also collected at GLEES in 1989. It has been reported in Park and Teton Counties and in Yellowstone National Park in NW Wyoming, and in Carbon County, Wyoming, which is closer to GLEES. *Carex bipartita* All., previously known only from Park and Johnson Counties in Wyoming, was collected at GLEES in 1990.

The complete GLEES vascular plant species checklist is presented in Appendix A. The list includes all plant species observed at GLEES from 1986 through 1990. Those plant species field identified in the initial habitat classification in 1986 and 1987, but not collected and identified in 1988–1990, are included in the checklist and specifically labeled as field identified only. They were not included in the calculations in tables 3.1, 3.2, and 3.3. It is expected that these species will be collected at GLEES and verified at a later date. Additional plant species also will likely be identified in the spruce-fir forest area at lower elevations of GLEES east of Brooklyn Lake.

Nomenclature follows that used by the Rocky Mountain Herbarium (Nelson and Hartman 1992). The primary references consulted for identification of plants, their distributions, and common names are listed below.

1) Primary taxonomic references for plant identifications:
   Dorn (1988)
   Hitchcock et al. (1955, 1959, 1961, 1964, 1969)
   Harrington (1964)
   Hermann (1970)
   Moss (1983)
   Nelson and Hartman (1992)

2) Major phytogeographical references:
   Rydberg (1914a, 1916, 1919)
   Great Plains Flora Association (1977, 1986)
   Harrington (1964)
   Hitchcock et al. (1955, 1959, 1961, 1964, 1969)
   Hulten and Fries (1986 a,b,c)
   Komarkova (1979)
   Martin and Hutchins (1980, 1981)
   Weber (1967, 1987, 1990)
   Welsh et al. (1987)

3) Primary references for common names:
   Beetle (1970)
   Duft and Moseley (1989)
   Harrington (1964)
   Hitchcock and Cronquist (1973)
   Hitchcock et al. (1955, 1959, 1961, 1964, 1969)
   Martin and Hutchins (1980, 1981)
   Nelson B.E. (1984)
   Nelson R.A. (1969)
   Porsild (1979)
   Rydberg (1954)
   Weber (1967, 1976)
   Welsh et al. (1987)

Secondary taxonomic literature sources were also used and are listed in the references section of this chapter. Each citation in the reference section is coded to indicate whether that reference was a phytogeographical reference (P), a common name reference (C), and/or a plant identification reference (I).

Primary References

Beetle, A.A. 1970. Recommended plant names. Research Journal 31. Laramie, WY: Agricultural Experiment Station, University of Wyoming. (C)

Dorn, R.D. 1988. Vascular plants of Wyoming. Cheyenne, WY: Mountain West Publishing. (I)

Duft, J.F.; Moseley, R.K. 1989. Alpine wildflowers of the Rocky Mountains. Missoula, MT: Mountain Press Publishing Company. 200 p. (C)

Great Plains Flora Association. 1977. Atlas of the flora of the Great Plains. Ames, IA: Iowa State University Press. 600 p. (P)

Great Plains Flora Association. 1986. Flora of the Great Plains. Lawrence, KS: University Press of Kansas. 1392 p. (P)

Harrington, H.D. 1964. Manual of the plants of Colorado, second edition. Chicago: Swallow Press. 666 p. (P,C,I)

Hermann, F.J. 1970. Manual of the carices of the Rocky Mountains and the adjacent Colorado Basin. Agriculture Handbook 374. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 397 p. (I)

Hitchcock, C.L.; Cronquist, A. 1973. Flora of the Pacific Northwest. Seattle: University of Washington Press. 730 p. (C)

Hitchcock, C.L.; Cronquist, A.; Ownbey, M.; Thompson, J.W. 1955. Vascular plants of the Pacific Northwest, part 5. Seattle: University of Washington Press. 343 p. (P,C,I)

Hitchcock, C.L.; Cronquist, A.; Ownbey, M.; Thompson, J.W. 1959. Vascular plants of the Pacific Northwest, part 4. Seattle: University of Washington Press. 510 p. (P,C,I)

Hitchcock, C.L.; Cronquist, A.; Ownbey, M.; Thompson, J.W. 1961. Vascular plants of the Pacific Northwest, part 3. Seattle: University of Washington Press. 614 p. (P,C,I)

Hitchcock, C.L.; Cronquist, A.; Ownbey, M.; Thompson, J.W. 1964. Vascular plants of the Pacific Northwest, part 2. Seattle: University of Washington Press. 597 p. (P,C,I)

Hitchcock, C.L.; Cronquist, A.; Ownbey, M.; Thompson, J.W. 1969. Vascular plants of the Pacific Northwest, part 1. Seattle: University of Washington Press. 914 p. (P,C,I)

Hulten, E.; Fries, M. 1986a. Atlas of North European vascular plants north of the Tropic of Cancer, volume 1. Konigstein, Germany: Koeltz Scientific Books. 498 p. (P)

Hulten, E.; Fries, M. 1986b. Atlas of North European vascular plants north of the Tropic of Cancer, volume 2. Konigstein, Germany: Koeltz Scientific Books. 968 p. (P)

Hulten, E.; Fries, M. 1986c. Atlas of North European vascular plants north of the Tropic of Cancer, volume 3. Konigstein, Germany: Koeltz Scientific Books. 1172 p. (P)

Komarkova, V. 1979. Alpine vegetation of the Indian Peaks area. Vaduz, Germany: J. Cramer. 591 p. (P)

Martin, W.C.; Hutchins, C.R. 1980. A flora of New Mexico, volume 1. Vaduz, Germany: J. Cramer. 1276 p. (P,C)

Martin, W.C.; Hutchins, C.R. 1981. A flora of New Mexico, volume 2. Vaduz, Germany: J. Cramer. 2591 p. (P,C)

Moss, E.H. 1983. Flora of Alberta, second edition (revised by John G. Packer). Toronto, Canada: University of Toronto Press. 687 p. (I)

Nelson, B.E. 1984. Vascular plants of the Medicine Bow Range. Laramie, WY: Jelm Mountain Press. 357 p. (C)

Nelson, B.E.; Hartman, R.L. 1992. Checklist of the vascular plants of Wyoming. [Unpublished]. Laramie: Rocky Mountain Herbarium, University of Wyoming. (I)

Nelson, R.A. 1969. Handbook of Rocky Mountain plants. Tucson, AZ: Dale Stuart King. 331 p. (C)

Porsild, A.E. 1979. Rocky Mountain wild flowers. Ottawa, Canada: National Museum of Natural Sciences, National Museums of Canada. 454 p. (C)

Rydberg, P.A. 1914a. Phytogeographical notes on the Rocky Mountain region. II. Origin of the alpine flora. Bulletin of the Torrey Botanical Club. 41: 89–103. (P)

Rydberg, P.A. 1916. Phytogeographical notes on the Rocky Mountain region. VI. Distribution of the subalpine plants. Bulletin of the Torrey Botanical Club. 43: 343–364. (P)

Rydberg, P.A. 1919. Phytogeographical notes on the Rocky Mountain region. VIII. Distribution of the montane plants. Bulletin of the Torrey Botanical Club. 46: 295–327. (P)

Rydberg, P.A. 1954. Flora of the Rocky Mountains. New York: Hafner Publishing. 1144 p. (C)

Weber, W.A. 1967. Rocky Mountain flora. Boulder: University of Colorado Press. 437 p. (P,C)

Weber, W.A. 1976. Rocky Mountain flora, fifth edition. Boulder: University of Colorado Press. 476 p. (C)

Weber, W.A. 1987. Colorado flora: Western Slope. Boulder, CO: Colorado Associated University Press. 530 p. (P)

Weber, W.A. 1990. Colorado flora: Eastern Slope. Boulder: University of Colorado Press. 396 p. (P)

Welsh, S.L.; Atwood, N.D.; Goodrich, S.; Higgins, L.C.; eds. 1987. A Utah flora. Great Basin Naturalist Memoirs 9. Provo, UT: Brigham Young University Press. 894 p. (P,C)

Secondary References

Anderson, K.L.; Owensby, C.E. 1969. Common names of a selected list of plants. Manhattan, KS: Agricultural Experiment Station, Kansas State University of Agriculture and Applied Science; Technical Bulletin 117. 62 p. (C)

Beetle, A.A.; May, M. 1971. Grasses of Wyoming. University of Wyoming Agricultural Experiment Station Research Journal. 39: 1–153. (I)

Budd, A.C. 1979. Budd's flora of the Canadian prairie provinces, revised and enlarged by J. Looman and K.F. Best. Research Branch Agriculture Canada Publication 1662. Hull, Quebec, Canada: Canadian Government Publishing Center. 863 p. (P)

Cronquist, A.; Holmgren, A.H.; Holmgren, N.H.; Reveal, J.L.; 1972. Intermountain flora, volume 1. New York: Hafner Publishing Company. 270 p. (P,C,I)

Cronquist, A.; Holmgren, A.H.; Holmgren, N.H.; Reveal, J.L.; Holmgren, P.K. 1977. Intermountain flora, volume 6. New York: Columbia University Press. 584 p. (P,C,I)

Cronquist, A.; Holmgren, A.H.; Holmgren, N.H.; Reveal, J.L.; Holmgren, P.K. 1984. Intermountain flora, volume 4. Bronx, NY: The New York Botanical Garden Press. 573 p. (P,C,I)

Cronquist, A.; Holmgren, A.H.; Holmgren, N.H.; Reveal, J.L.; Holmgren, P.K. 1989. Intermountain flora, volume 3. Bronx, NY: The New York Botanical Garden Press. 279 p. (P,C,I)

Dorn, R.D. 1977. Manual of the vascular plants of Wyoming, volume I. New York: Garland Publishing. 801 p. (I)

Dorn, R.D. 1977. Manual of the vascular plants of Wyoming, volume II. New York: Garland Publishing. 802–1498 p. (I)

Frohne, D.; Pfander, H.J. 1983. A color atlas of poisonous plants. London: Wolfe Publishing. 291 p. (C)

Fuller, T.C.; McClintock, E. 1986. Poisonous plants of California. California Natural History Guides 53. Berkeley: University of California Press. 433 p. (C)
Gillett, J.M. 1965. Taxonomy of trifolium: five American species of section lupinaster (*Leguminosae*). Brittonia. 17(2): 121–136. (I)
Gleason, H.A. 1952. The New Britton and Brown illustrated flora of the northeastern United States and adjacent Canada, volume 1. Lancaster, PA: Lancaster Press. 482 p. (P)
Gleason, H.A. 1952. The New Britton and Brown illustrated flora of the northeastern United States and adjacent Canada, volume 2. Lancaster, PA: Lancaster Press. 655 p. (P)
Gleason, H.A. 1952. The New Britton and Brown illustrated flora of the northeastern United States and adjacent Canada, volume 3. Lancaster, PA: Lancaster Press. 589 p. (P)
Gleason, H.A.; Cronquist, A. 1991. Manual of the vascular plants of northeastern United States and adjacent Canada, second edition. Bronx, NY: The New York Botanical Garden Press. 910 p. (P,C)
Gray, A.; Hooker, J.D. 1880. The vegetation of the Rocky Mountain region and a comparison with that of other parts of the world. Bulletin of the United States Geological and Geographical Survey of the Territories. 6(1):1–62. (P)
Harshburger, J.W. 1911. Phytogeographic survey of North America. Vegetation d. Erde 13 63. Engelmann, Weinheim. 790 pp. (P)
Holm, T. 1923. The vegetation of the alpine region of the Rocky Mountains in Colorado. Memoirs of the National Academy of Sciences. 19(3): 1–45. (P)
Hulten, E. 1968. Flora of Alaska and neighboring territories. Stanford, CA: Stanford University Press. 1008 p. (P)
Kearney, T.H.; Peebles, R.H. 1964. Arizona flora. Berkeley, CA: University of California Press. 1085 p. (P)
Moore, D.M. 1982. Flora Europaea check-list and chromosome index. Cambridge, England: Cambridge University Press. 423 p. (P)
Muenscher, W.C. 1939. Poisonous plants of the United States. New York: MacMillan. 266 p. (C)
Ownbey, G.B.; Morley, T. 1991. Vascular plants of Minnesota, a checklist and atlas. Minneapolis, MN: University of Minnesota Press. 308 p. (P)
Porsild, A.E.; Cody, W.J. 1979. Vascular plants of continental northwest territories, Canada. Ottawa, Canada: National Museum of Natural Sciences, National Museums of Canada. 667 p. (P)
Rydberg, P.A. 1913. Phytogeographical notes on the Rocky Mountain region. I. Alpine region. Bulletin of the Torrey Botanical Club. 40: 677–686. (P)
Rydberg, P.A. 1914b. Phytogeographical notes on the Rocky Mountain region. III. Formations in the alpine zone. Bulletin of the Torrey Botanical Club. 41: 459–474. (P)
Rydberg, P.A. 1915a. Phytogeographical notes on the Rocky Mountain region. IV. Forests of the subalpine and montane zones. Bulletin of the Torrey Botanical Club. 42: 11–25. (P)
Rydberg, P.A. 1915b. Phytogeographical notes on the Rocky Mountain region. V. Grasslands of the subalpine and montane zones. Bulletin of the Torrey Botanical Club. 42: 629–642. (P)
Rydberg, P.A. 1917. Phytogeographical notes on the Rocky Mountain region. VII. Formations in the subalpine zone. Bulletin of the Torrey Botanical Club. 44: 431–454. (P)
Rydberg, P.A. 1920. Phytogeographical notes on the Rocky Mountain region. IX. Wooded formations of the montane zone of the southern Rockies. Bulletin of the Torrey Botanical Club. 47: 441–454. (P)
Rydberg, P.A. 1921. Phytogeographical notes on the Rocky Mountain region. X. Grasslands and other open formations of the montane zone of the southern Rockies. Bulletin of the Torrey Botanical Club. 48: 315–326. (P)
Taylor, R.L.; MacBryde, B. 1977. Vascular plants of British Columbia, a descriptive resource inventory. The Botanical Garden Technical Bulletin 4. Vancouver, British Columbia: University of British Columbia Press. 754 p. (P)
Weber, W.A. 1965. Plant geography in the southern Rocky Mountains. In: Wright, H.E., Jr. and Frey, D.G., eds. The Quaternary of the United States. Princeton, NJ: Princeton University Press: 453–468. (P)
Weber, W.A.; Wittmann, R.C. 1992. Catalog of the Colorado flora: a biodiversity baseline. Niwot, CO: University Press of Colorado. 215 p. (I)
Welsh, S.L. 1974. Anderson's flora of Alaska and adjacent parts of Canada. Provo, UT: Brigham Young University Press. 724 p. (P,C)

4. GEOLOGY

E. A. Rochette
University of Wyoming
Laramie, Wyoming

Precambrian History

The Medicine Bow Mountains have a core of Precambrian rocks. They contain the boundary, the Cheyenne Belt, between the Wyoming Province to the NW and the accreted Proterozoic continental crust to the SE (Karlstrom and Houston 1984). The Wyoming Province consists of Archean rocks that are locally intruded and (or) overlain by rocks of Proterozoic age, including the lithologies present in the West Glacier Lake drainage basin.

The Precambrian tectonic history of the Medicine Bow Mountains is described in detail by Karlstrom and Houston (1984). The Medicine Peak Quartzite found in the West Glacier Lake drainage basin was deposited as part of the Snowy Pass Supergroup between 2000 and 2300 million years (My) ago in a widening rift-formed, passive-margin basin. The widening of the basin included faulting in the underlying Archean rocks. Faults gave access to mafic dikes, which intruded as high as the Lower Libby Creek Group, including the Medicine Peak Quartzite. These dikes make up an estimated 15% to 20% of the bedrock in the Glacier Lakes and Lost Lake drainage basins.

Regional metamorphism in the Medicine Bow Mountains took place between 1650 and 1700 My ago during the main collision of the Wyoming Province with island arcs to the SE. The mineralogy of the mafic dikes indicates that this metamorphism was greenschist facies (Karlstrom and Houston 1984).

Petrology of Rock Units in the Study Area

The bedrock in the study area is the Medicine Peak Quartzite that is intruded by mafic dikes. The Medicine Peak Quartzite is a 1700-m-thick complex of braided fluvial deposits interfingering with tide-dominated delta plain sediments (Flurkey 1983). Lenses of schist in the quartzite were probably local clay deposits within the unit. Mineralogically the bulk rock, not including the schist lenses, can be described as follows:

1) 60–100% quartz
2) phyllosilicates up to 38%: sericite (potassium end-member), local chromium-bearing sericite (fuchsite), kaolinite, and pyrophyllite
3) up to 25% kyanite
4) 3% feldspar: mainly albite plagioclase with an average anorthite content of 7%; potassium feldspar does not exceed 30% of feldspar
5) opaque minerals up to 8% occur in colors of red, steel gray, white, and yellow
6) accessory heavy minerals, including zircon, tourmaline, and, rarely, apatite (Flurkey 1983)

Thin sections of quartzite collected in the study area agree with Flurkey's descriptions. Color banding in rocks of the study area results from layers containing kyanite, sometimes with phyllosilicates, and occasionally opaque minerals.

Weight percentages for major oxides in mafic rocks were calculated based on mineralogic point count data and agreed reasonably well with those from bulk rock analyses. Mafic rocks consist of approximately:

1) 44% actinolite;
2) 30% epidote;
3) 7–15% albite;
4) up to 7% quartz;
5) up to 5% chlorite;
6) up to 4% sphene;
7) up to 2% biotite;
8) less than 0.5% opaques, including chromite and (or) magnetite and pyrite.

Karlstrom and Houston (1984) describe these dikes as gabbroic, although they are referred to as metadiabase by Oviatt (1977). In this report, the dikes are generally referred to as mafic dikes. Bulk chemical analyses for both the mafic rocks and quartzite, as well as mineral compositions measured by electron microprobe, are given in Rochette (1987).

Cenozoic History

During the Paleocene, Laramide deformation defined the Medicine Bow Mountains and uplift kept pace with erosion, which stripped Phanerozoic sediments where Precambrian rocks are now exposed (Blackstone 1975, Houston et al. 1978). Quaternary and Holocene glaciation sculpted the Snowy Range to its present geomorphology and left till of local bedrock in the Glacier Lakes area; soil development began as glaciation ended.

It appears that the study area was included in the collection area of the Libby Glacier, by comparison with work by Atwood (1937) and Mears (1953). The Libby Glacier collected in an area east of Browns Peak and to the north along the east of the range, and flowed to the east along Libby Creek.

It is assumed that present soils in the drainage basin are in equilibrium with the present climate. Work by Sansom (1972) on Pinedale moraines of the Libby Creek area supports this assumption. Sansom found no clear trends in soil properties to relate moraine age to soil maturity and concluded that present soils are in equi-

librium with the present climate. He suggested that the severity and short duration of climates was the reason that expression of historic climates in the soils is not seen.

Presently in the Snowy Range there are no glaciers. However, there are permanent snowfields, such as the one that feeds West Glacier Lake. Mears (1953) reported a contemporary orographic snowline of 11,000 ft (3353 m). This value is consistent with the snowfields in the West Glacier Lake drainage basin.

In summary (based on work by Oviatt 1977, Benedict 1973, Breckenridge 1969, McCallum 1962), tills in the Glacier Lakes area are probably late Pinedale in age, so soil formation probably began in the West Glacier drainage basin around 10,000 before present (B.P.). The Altithermal probably did not significantly affect regions as high in the range as the study area, so no concentrated calcium carbonate horizons are expected in the soils. Soils formation may have been interrupted to some extent around 1900 B.P., when protalus ramparts formed (protalus ramparts suggest the presence of ancient snowfields, Flint 1971). Finally, soils genetically related to the local bedrock in the watershed should be forming in the present climate. Chemical weathering in the West Glacier Lake drainage has been described in detail elsewhere (Rochette 1987, Rochette et al. 1988). A map describing the general geology of GLEES is provided in figure 4.1.

References

Atwood, W.W., Jr. 1937. Records of Pleistocene glaciers in the Medicine Bow mountains and park ranges. Journal of Geology. 45: 114–140.

Benedict, J.B. 1973. Chronology of cirque glaciation, Colorado Front Range. Quaternary Research. 3: 584–599.

Blackstone, D.L., Jr. 1975. Late Cretaceous and Cenozoic history of Laramie basin region, southeast Wyoming. Geological Society of America Memoir. 144: 249–279.

Breckenridge, R.M. 1969. Neoglacial geology of Fall Creek Basin, Mummy Range, Colorado. Laramie: University of Wyoming. 59 p. M.S. thesis.

Flint, R.F. 1971. Glacial and quaternary geology. New York: John Wiley and Sons, 892 p.

Flurkey, A.J. 1983. Depositional environment and petrology of the Medicine Peak quartzite (early Proterozoic), southern Wyoming. Laramie, WY: University of Wyoming. 125 p. Ph.D. Dissertation.

Houston, R.S. et al. 1978. A regional study of rocks of Precambrian age in that part of the Medicine Bow Mountains lying in southeastern Wyoming. Geological Survey of Wyoming Memoir No. 1, 167 pp. and map.

Karlstrom, K.E.; Houston, R.S. 1984. The Cheyenne belt: Analysis of a Proterozoic structure in southern Wyoming. Precambrian Research. 25: 415–446.

McCallum, M.E. 1962. Quaternary features of the Medicine Bow mountains, southeastern Wyoming. Contributions to Geology. 1: 21–29.

Mears, B., Jr. 1953. Quaternary features of the Medicine Bow mountains, Wyoming. In: Wyoming Geology Association Guidebook: 8th annual field conference; July 29-Aug 1, 1953. Laramie Basin, Wyoming and North Park, Colorado. Casper, Wyoming: Wyoming Geological Society: 81–84.

Oviatt, C.G. 1977. Glacial geology of the Lake Marie area, Medicine Bow mountains, Wyoming. Laramie: University of Wyoming. 82 p. M.S. thesis.

Rochette, E.A. 1987. Chemical weathering in the West Glacier Lake drainage basin, Snowy Range, Wyoming: Implications for future acid deposition. Laramie: University of Wyoming. 138 p. M.S. thesis.

Rochette, E.A.; Drever, J.I.; Sanders, F.S. 1988. Chemical weathering in the West Glacier Lake drainage basin, Snowy Range, Wyoming: Implications for future acid deposition. Contributions to Geology. 26: 29–44.

Sansom, B.R. 1972. Morphology and analysis of soils on Wisconsin moraines of the Libby Creek area, Medicine Bow mountains, Wyoming. Laramie: University of Wyoming. 78 p. M.S. thesis.

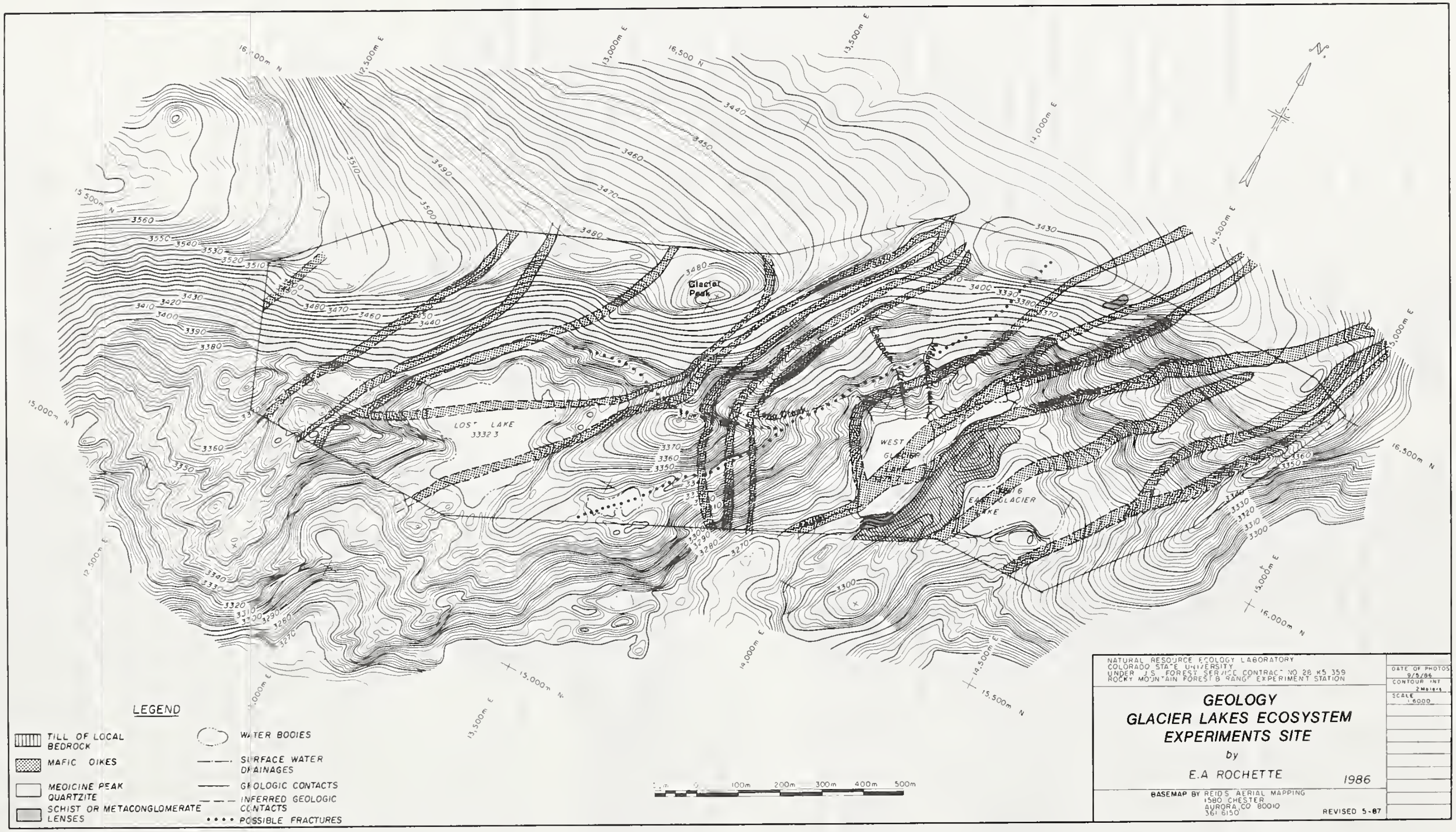


Figure 4.1.—Geological map of the GLEES.

5. SOILS

R.W.E. Hopper and P.M. Walthall
Agronomy Department, Colorado State University
Fort Collins, Colorado

This report describes the soils of the Lost Lake, West Glacier Lake, and East Glacier Lake watersheds of GLEES and presents the methods used in conducting both the field and laboratory work. In addition, general statements about the nature of the mapping units used in making the soil maps are provided.

Appendix D presents the soil map unit descriptions. The pedon descriptions for representative soil pedons of the Glacier Lakes and Lost Lake watersheds are listed in Appendix E. Included in tabular form in this chapter are the physical and chemical characterization data for these soil pedons. The soils map is presented in figure 5.1.

Methods and Definitions

Soil Survey Methods

Field procedures appropriate for making an Order 3 soil survey were used in conducting the soil mapping (USDA, SCS 1984). These guidelines were exceeded in several respects, so that the finished soil maps approach those produced in an Order 2 soil survey. A detailed geology map (Rochette 1987) of the survey area permitted increased resolution of critical locations of mafic intrusive rock types and thus allowed design of soil mapping units that recognized their presence.

Map unit composition was determined by transecting selected delineations of the mapping units. The information from these transects provided estimates of the proportional amounts of the named components of the map units, as well as the soil and land types that are included in most delineations of a given map unit. The boundaries of each mapping unit were observed throughout much of their length. Notes on soil morphological characteristics and landform setting were recorded.

Representative pedon descriptions were chosen following mapping in most cases so that the variability in morphological characteristics for a given soil type could be considered. Pedons selected to be representative of the major soils in the map units were described in de-

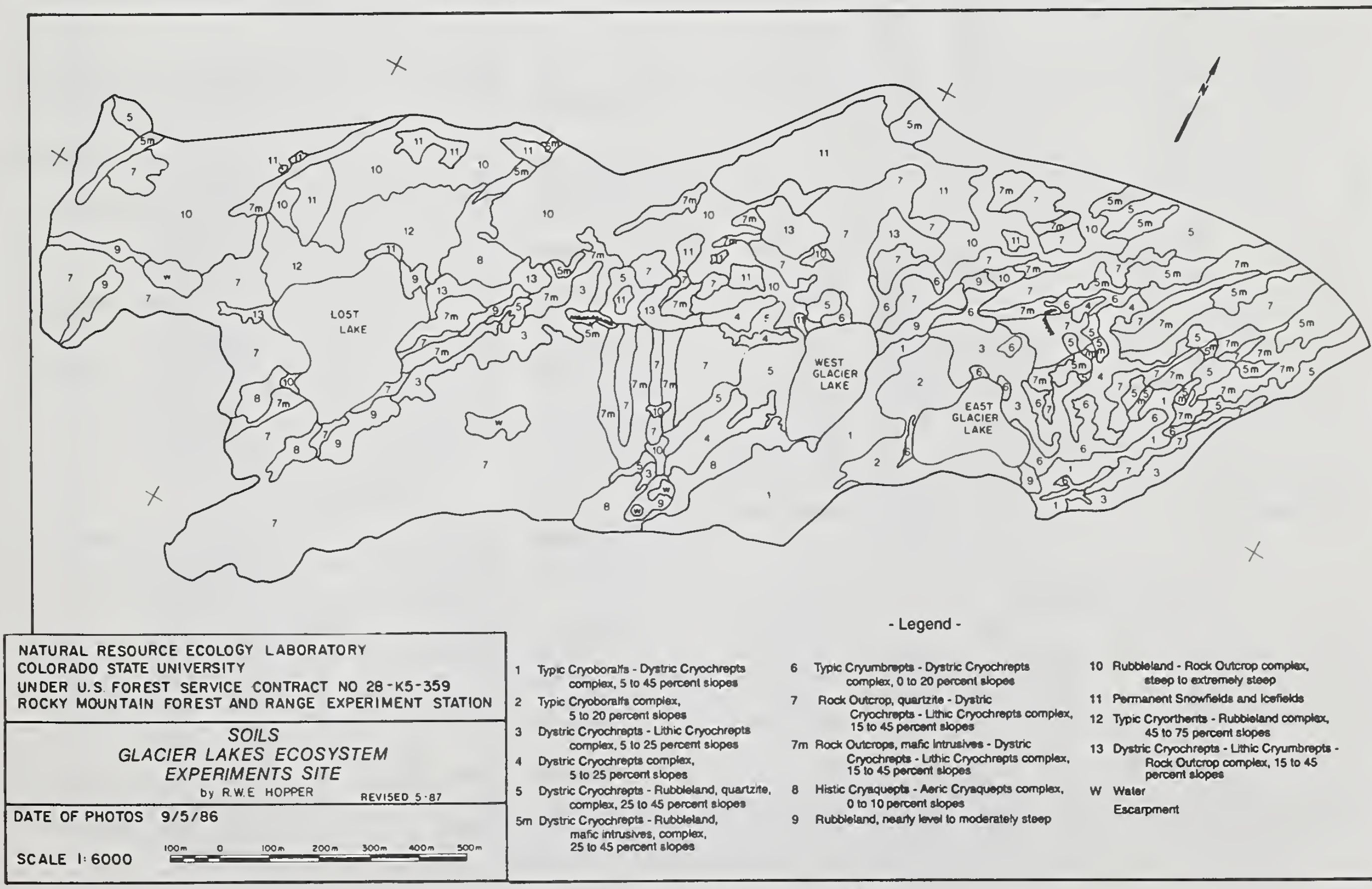


Figure 5.1.—Soils map of GLEES.

tail (USDA, SCS 1981) and sampled for physical and chemical laboratory characterization. Pedons of major soils and inclusions were classified in accordance with *Soil Taxonomy* (Soil Survey Staff 1975).

Laboratory Analyses

Soil samples were analyzed utilizing facilities of the Agronomy Department, Colorado State University, using accepted standard analytical procedures. These analyses included the following:

1) Particle size distribution in the fine-earth fraction was determined using the Bouyoucos hydrometer method (Day 1965).
2) Unbuffered, neutral salt, extraction of exchangeable bases and exchange acidity followed the NH_4Cl and KCl extraction methods (Arberg 1985).
3) Buffered (pH 8.2) extraction of exchange acidity followed the $BaCl_2$-triethanolamine extraction method (Arberg 1985).
4) pH was determined in water and 0.01*M* $CaCl_2$ (Arberg 1985). Determinations for mineral material were conducted at a soil-to-liquid ratio of 1:1. Determinations for organic soil material were conducted at 1:5 dilution.
5) Organic carbon contents were determined by a wet oxidation and diffusion method (Snyder and Trofymow 1984).

The results of these analyses appear in tables 5.1 and 5.2.

Table 5.1.—pH-transect data at GLEES.

Map unit no.	Component subgroup classif.	Hor.	Upper depth (cm)	Lower depth (cm)	pH (0.01M $CaCl_2$)	pH (water)	Elev. (m)	Slope (%)
			pH Transect no. 1					
5	Ochrept	A	0	4	4.36	4.77	3386	50
		Bw	4	27	4.23	4.88		
5	Ochrept	A	0	5	4.54	5.16	3378	44
		Bw	5	18	4.12	4.77		
5	Ochrept	A	0	6	4.22	4.87	3374	47
		Bw	6	23	4.19	4.43		
5	Ochrept	A	0	5	4.29	4.84	3365	47
		Bw	5	21	4.01	4.74		
5	Ochrept	A	0	6	3.49	4.16	3356	22
		Bw	6	25	3.65	4.24		
7m	Ochrept	A&BA	0	6	3.73	4.23	3353	24
		Bw	6	32	3.60	4.17		
			pH transect no. 1					
6	Umbrept	A&BA	0	19	3.83	4.36	3348	7
		Bw	19	39	3.83	4.35		
6	Ochrept	A	0	5	4.03	4.50	3346	10
		Bw	5	29	3.86	4.35		
5	Ochrept	A	0	4	4.22	4.61	3345	10
		Bw	4	22	3.77	4.30		
4	Ochrept	A	0	4	4.08	4.57	3343	25
		E&EB	4	22	3.55	4.23		
		Bw	22	31	3.52	4.10		
7	Ochrept	A	0	4	4.34	4.88	3340	33
		BE	4	29	3.97	4.45		
7	Ochrept	A	0	3	4.22	4.70	3334	34
		Bw	3	26	3.97	4.44		
5		Quartzite rock outcrop					3330	52
5	Ochrept	A	0	6	3.91	4.47	3307	12
		Bw	6	22	3.97	4.54		
5	Ochrept	BA	0	10	4.01	4.67	3305	8
		BEb	10	26	3.98	4.69		
4	Ochrept	Oi&A	3	9	4.00	4.70	3302	24
		EB	9	34	3.69	4.25		
6	Ochrept	A&EB	0	17	3.94	4.39	3299	13
		Bw	17	29	3.69	4.06		
6	Umbrept	A	0	19	3.82	4.25	3296	13
		Bw	19	35	3.82	4.38		
			pH transect no. 1					
4	Ochrept	Oi&Oa	11	0	4.39	4.80	3292	16
		Bw	0	25	4.55	5.02		
6	Aquept	A	0	8	3.85	4.30	3290	2
		Bw	8	31	3.69	4.31		
			pH transect no. 2					
7	Ochrept	A&E	0	9	3.89	4.54	3340	35
		Bw	9	22	3.86	4.70		
7	Ochrept	A	0	12	4.08	4.95	3328	36
		BE	12	28	4.08	4.88		
5	Ochrept	A	0	7	4.14	4.96	3316	29
		BE	7	21	4.09	5.01		
5	Ochrept	A/B	0	11	4.00	4.75	3310	22
		BE	11	28	3.97	4.83		
5	Ochrept	A	0	4	4.04	4.67	3305	23
		BE	4	25	3.97	4.86		
4	Ochrept	Oi&O	6	0	4.32	5.46	3300	16
		E	0	8	3.95	4.66		
		BE	8	25	3.97	4.83		
8	Umbrept	A	0	26	3.90	4.72	3290	10
		E	26	33	3.85	4.89		
8	Aquept	Oa	21	0	3.80	4.65	3280	3
		Bg	0	15	3.90	4.93		
			pH transect no. 3					
1	Umbrept	Oa	6	0	4.72	5.27	3292	30
		Bw	0	21	4.27	5.09		
1	Boralf	Oi&Oa	5	0	4.49	5.18	3295	30
		EB&Bt	0	21	3.51	4.20		
1	Boralf	Oi&O	15	0	4.76	5.25	3298	26
		E&EB	0	15	4.00	4.65		
1	Ochrept	Oi&Oa	5	0	4.70	5.26	3299	30
		A&EB	0	22	3.71	4.39		
1	Boralf	A	0	8	3.69	4.35	3301	10
		E	8	22	3.59	4.36		
1	Ochrept	Oi&O	12	0	5.66	6.17	3307	35
		E	0	19	4.43	5.09		
1	Boralf	Oi&O	5	0	4.40	4.99	3310	9
		E	5	17	3.73	4.42		

TABLE 5.2.—Physical and chemical characterization data for representative soil pedons at GLEES.

Pedon Number and Classification	Sample No.	Horizon	Upper Horizon Depth (cm)	Lower Horizon Depth (cm)	(%) Sand	(%) Silt	(%) Clay (<2mm)	(%) Sand (clay free)	(%) Silt (clay free)	Exchangeable Bases (meq/100 gm)				Exchange Acidity (meq/100 gm)			Cation Exchange Capacity (unbuffered, meq/100 gm)	(%) Base Saturation (unbuffered, meq/100 gm)	pH Water	pH 0.01M CaCl2	(pH 8.2 buffered) (meq/100 gm)		(%) Base Saturation	(%) Organic Carbon
										Ca	Mg	Na	K	Al	H	Total					Cation Exchange Capacity	Exchange Acidity		
GLACIER LAKES WATERSHED																								
WYGL001	WYGL0011	Oi & Oa	2	0	—	—	—	—	—	22.58	2.52	0.03	0.55	0.03	0.67	0.97	26.64	96.36	3.35	3.99	81.35	55.68	31.56	>24.00
	WYGL0012	E	0	3	31.5	37.1	31.5	45.9	54.1	1.18	0.29	0.05	0.19	8.36	2.10	10.46	12.18	14.06	3.62	3.09	25.43	23.72	6.73	3.15
Typic Cryoboralf	WYGL0013	2E9	3	11	52.7	32.5	14.8	61.9	38.1	0.32	0.20	0.03	0.08	5.93	3.00	8.93	9.56	6.64	3.69	3.00	15.34	14.71	4.14	1.14
	WYGL0014	2Bt	11	31	60.8	24.4	14.8	71.3	28.7	0.74	0.68	0.02	0.04	6.45	3.49	9.94	11.41	12.92	3.73	3.01	16.67	15.19	8.95	0.50
	WYGL0015	2BC1	31	66	44.5	34.6	20.9	56.3	43.7	0.77	0.55	0.01	0.03	5.53	4.12	9.65	11.01	12.35	3.85	3.10	16.10	14.74	8.44	0.36
	WYGL0016	2BC2	66	100	57.1	26.2	16.7	68.5	31.5	0.34	0.27	0.00	0.02	3.42	1.11	4.53	5.17	12.37	3.92	3.19	9.95	9.31	6.43	0.18
WYGL002	WYGL0021	Oi & Oa	2	0	—	—	—	—	—	18.51	2.51	0.03	0.42	0.07	0.22	0.30	21.76	98.64	4.30	4.05	56.13	34.67	38.24	14.05
	WYGL0022	E	0	8	63.1	24.2	12.7	72.3	27.7	1.92	0.50	0.00	0.06	1.56	1.04	2.60	5.08	48.78	3.62	3.37	10.68	8.20	23.21	2.85
Typic Cryoboralf	WYGL0023	EB	8	16	59.1	28.2	12.7	67.7	32.3	1.04	0.34	0.00	0.03	1.66	1.39	3.05	4.47	31.72	3.65	3.32	8.62	7.20	16.44	0.46
	WYGL0024	BE	16	25	53.0	30.3	16.7	63.6	36.4	0.84	0.33	0.00	0.03	2.77	0.77	3.54	4.75	25.41	3.60	3.25	11.93	10.72	10.12	1.68
	WYGL0025	Bt	25	47	57.0	24.3	18.8	70.1	29.9	0.63	0.28	0.00	0.03	3.55	1.48	5.03	5.98	15.77	3.64	3.20	14.69	13.74	6.42	0.54
	WYGL0026	BC1	47	61	55.1	28.2	16.7	66.2	33.8	0.26	0.13	0.02	0.03	2.51	0.89	3.40	3.85	11.71	3.70	3.30	7.34	6.89	6.14	0.32
	WYGL0027	BC2	61	73	55.2	28.2	16.7	66.2	33.8	0.12	0.08	0.01	0.02	2.10	0.82	2.92	3.15	7.37	3.81	3.40	7.12	6.89	3.26	0.24
	WYGL0028	BC3	73	101	59.2	24.1	16.7	71.0	29.0	0.12	0.07	0.00	0.02	2.03	0.85	2.88	3.09	6.89	3.84	3.42	7.95	7.73	2.68	0.18
WYGL003	WYGL0031	A	0	2	44.4	32.6	23.0	57.6	42.4	6.80	1.90	0.02	0.26	0.00	0.10	0.10	9.08	98.87	5.50	5.05	15.45	6.47	58.10	2.57
	WYGL0032	2Bw	2	30	77.3	10.1	12.6	88.5	11.5	1.62	0.73	0.03	0.07	0.33	0.32	0.64	3.08	79.14	4.94	4.23	7.48	5.04	32.63	0.33
Dystric Cryochrept	WYGL0033	2BC	24	47	64.5	24.2	11.4	72.7	27.3	0.75	0.44	0.01	0.02	1.17	0.49	1.66	2.89	42.58	4.45	3.78	6.27	5.04	19.58	0.24
	WYGL0034	3C	46	59	44.3	42.3	13.4	51.1	48.9	0.61	0.36	0.02	0.02	1.24	0.53	1.77	2.79	36.42	4.71	3.69	8.62	7.60	11.79	0.27
WYGL004	WYGL0041	A	0	3	49.7	28.6	21.7	63.5	36.5	4.51	1.00	0.02	0.11	1.41	0.58	1.99	7.64	73.92	4.48	3.90	20.76	15.11	27.22	2.36
	WYGL0042	CA	3	24	41.7	36.6	21.6	53.3	46.7	3.08	0.76	0.03	0.08	2.33	0.87	3.19	7.15	55.29	4.39	3.73	17.58	13.63	22.48	1.86
Typic Cryorthent	WYGL0043	C1	24	46	51.9	28.5	19.6	64.5	35.5	2.79	0.69	0.02	0.06	2.73	0.99	3.72	7.28	48.91	4.38	3.68	12.91	9.35	27.59	1.04
	WYGL0044	C2	46	64	62.2	20.3	17.5	75.4	24.6	2.01	0.48	0.03	0.04	2.01	1.24	3.25	5.80	43.97	4.30	3.61	18.85	16.30	13.52	0.77
WYGL005	WYGL0051	Oi & Oa	3	0	—	—	—	—	—	40.38	3.33	0.05	0.59	0.03	0.39	0.42	44.77	99.07	4.74	4.29	83.87	39.51	52.88	21.82
	WYGL0052	E	0	9	56.2	30.3	13.4	65.0	35.0	1.69	0.30	0.02	0.11	2.48	1.17	3.64	5.75	36.67	3.81	3.22	4.72	2.61	44.70	0.91
Typic Cryorthent	WYGL0053	BE	9	17	62.4	24.2	13.4	72.1	27.9	0.73	0.20	0.01	0.04	2.22	1.56	3.79	4.76	20.39	3.53	3.10	6.92	5.95	14.01	0.53
	WYGL0054	Bw	17	43	54.4	30.2	15.4	64.3	35.7	0.25	0.14	0.01	0.03	2.64	0.00	1.90	2.32	18.39	3.75	3.10	7.13	6.70	5.99	0.37
	WYGL0055	BC1	43	64	52.2	28.3	19.5	64.8	35.2	0.34	0.21	0.00	0.03	4.07	2.18	6.25	6.82	8.43	3.82	3.20	8.90	8.33	6.46	0.33
	WYGL0056	BC2	74	105	54.2	28.3	17.5	65.7	34.3	0.22	0.28	0.02	0.04	4.18	0.00	3.18	3.75	15.16	4.49	3.64	8.75	8.18	6.50	0.20
WYGL006	WYGL0061	A	0	5	41.0	39.0	20.0	51.0	49.0	10.59	2.04	0.03	0.40	0.12	3.19	3.31	16.35	79.79	4.68	4.20	33.09	20.04	39.43	6.93
	WYGL0062	E	5	9	43.8	38.6	17.6	53.2	46.8	5.54	1.12	0.05	0.11	0.97	0.58	1.55	8.36	81.43	4.10	3.70	15.28	8.47	44.57	1.67
Dystric Cryochrept	WYGL0063	BE	9	13	54.0	28.5	17.6	65.5	34.5	6.18	1.18	0.02	0.05	0.80	1.39	2.20	9.64	77.20	4.02	3.73	14.95	7.51	49.76	1.65
	WYGL0064	Bw	13	23	45.4	32.9	21.8	58.0	42.0	9.61	1.93	0.07	0.05	1.24	0.32	1.55	13.21	88.24	4.45	3.87	22.40	10.74	52.05	0.91
	WYGL0065	BC	23	41	50.4	36.3	13.4	58.1	41.9	2.67	0.58	0.01	0.03	0.00	0.67	0.67	3.96	83.13	4.05	3.65	6.34	3.05	51.90	0.44
	WYGL0066	C1	41	74	56.5	34.1	9.3	62.4	37.6	1.41	0.30	0.00	0.02	0.37	0.31	0.68	2.41	71.70	4.01	3.68	3.77	2.04	45.80	0.18
	WYGL0067	C2	74	101	58.6	32.1	9.3	64.6	35.4	1.43	0.28	0.03	0.02	0.33	0.00	0.00	1.76	100.00	4.09	3.70	3.60	1.84	48.84	0.25
WYGL007	WYGL0071	Oi & Oa	4	0	—	—	—	—	—	39.25	3.58	0.03	0.45	0.00	0.31	0.31	43.62	99.29	4.62	4.10	88.26	44.95	49.07	>24.00
	WYGL0072	E	0	10	32.9	39.1	28.0	45.7	54.3	4.06	0.79	0.03	0.10	4.87	0.62	5.50	10.48	47.55	4.20	3.45	19.52	14.54	25.53	1.78
Dystric Cryochrept	WYGL0073	BE	10	26	39.3	36.8	23.8	51.6	48.4	2.19	0.50	0.03	0.09	4.64	1.33	5.97	8.79	32.07	4.11	3.30	17.60	14.78	16.02	1.44
	WYGL0074	B	26	55	47.4	30.8	21.8	60.6	39.4	1.09	0.25	0.02	0.06	5.10	1.08	6.19	7.60	18.59	3.99	3.35	20.81	19.39	6.79	1.36
	WYGL0075	BC1	55	85	51.7	28.6	19.7	64.4	35.6	0.46	0.09	0.02	0.05	2.86	0.77	3.64	4.25	14.43	4.27	3.65	19.17	18.55	3.20	1.14
	WYGL0076	BC2	85	106	51.7	26.6	21.7	66.1	33.9	0.42	0.10	0.07	0.05	2.47	3.02	5.49	6.14	10.47	4.12	3.64	16.91	16.27	3.90	1.24
WYGL008	WYGL0081	A	0	21	41.4	38.9	19.7	51.5	48.5	6.53	1.61	0.00	0.19	0.60	0.38	0.97	9.31	89.55	4.60	4.13	18.39	10.06	45.31	2.05
	WYGL0082	AC	21	51	39.6	40.8	19.7	49.3	50.7	6.42	1.51	0.02	0.04	1.17	0.57	1.74	9.73	82.15	4.39	3.99	13.61	5.61	58.74	0.62
Typic Cryorthent	WYGL0083	C1	51	73	52.1	36.4	11.4	58.9	41.1	4.84	1.13	0.03	0.03	0.26	0.78	1.04	7.07	85.26	4.75	4.20	10.04	4.02	60.00	0.16
	WYGL0084	2C2	73	92	64.5	26.2	9.3	71.1	28.9	3.07	0.73	0.01	0.02	0.14	0.59	0.74	4.57	83.92	5.32	4.40	6.23	2.40	61.58	0.11
WYGL009	WYGL0091	A	0	8	40.0	47.7	12.3	45.6	54.4	2.39	0.45	0.05	0.11	4.97	1.36	6.22	9.21	32.46	3.89	3.40	31.48	28.49	9.50	6.03
	WYGL0092	Bw	8	45	44.7	34.9	20.4	56.2	43.8	0.36	0.05	0.01	0.06	3.57	1.30	4.87	5.35	9.08	3.89	3.50	18.63	18.14	2.61	1.90
Typic Cryumbrept	WYGL0093	BC	45	84	53.3	28.5	18.2	65.2	34.8	0.15	0.03	0.05	0.02	2.74	0.85	3.59	3.85	6.59	4.05	3.60	15.46	15.21	1.64	0.39
	WYGL0094	2C	84	110	26.8	51.0	22.3	34.4	65.6	1.46	0.31	0.02	0.04	5.36	0.52	5.89	7.72	23.72	4.29	3.59	15.59	13.76	11.74	0.23
	WYGL0095*	BC	45	84	67.9	20.1	11.9	77.1	22.9	0.28	0.04	0.03	0.03	1.78	0.23	2.01	2.39	16.02	3.70	3.51	8.77	8.39	4.37	1.13

TABLE 5.2.—(Continued)

Pedon Number and Classification	Sample No.	Horizon	Upper Horizon Depth (cm)	Lower Horizon Depth (cm)	(%) Sand	(%) Silt	(%) Clay (<2mm)	(%) Sand (clay free)	(%) Silt (clay free)	Exchangeable Bases (meq/100 gm) Ca	Mg	Na	K	Exchange Acidity (meq/100 gm) Al	H	Total	Cation Exchange Capacity (unbuffered, meq/100 gm)	(%) Base Saturation (unbuffered, meq/100 gm)	pH Water	pH 0.01M CaCl2	(pH 8.2 buffered) (meq/100 gm) Cation Exchange Capacity	Exchange Acidity	(%) Base Saturation	(%) Organic Carbon
WYGL010	WYGL0101	A	0	9	28.1	46.6	25.3	37.6	62.4	4.70	1.18	0.10	0.20	5.51	1.89	7.39	13.57	45.51	3.83	3.49	39.61	33.43	15.60	7.46
	WYGL0102	B	9	30	30.8	44.1	25.0	41.1	58.9	1.10	0.20	0.05	0.06	6.54	0.56	7.11	8.52	16.54	3.90	3.35	27.00	25.59	5.22	2.38
Typic Cryumbrept	WYGL0103	BC	30	59	24.7	39.8	35.5	38.3	61.7	1.25	0.22	0.04	0.05	5.98	0.76	6.74	8.29	18.73	3.92	3.09	25.32	23.76	6.14	1.74
	WYGL0104	2C1	59	91	74.0	16.1	9.9	82.1	17.9	0.23	0.05	0.01	0.02	1.03	2.14	3.17	3.48	8.99	4.10	3.70	5.65	5.34	5.54	0.26
	WYGL0105	2C2	91	108	60.3	26.3	13.4	659.7	30.3	0.32	0.04	0.02	0.01	0.89	0.13	1.02	1.41	27.53	4.10	3.60	4.90	4.51	7.94	0.19
WYGL011	WYGL0111	A1	0	11	40.1	37.6	22.2	51.6	48.4	7.77	1.62	0.12	0.21	1.54	0.64	2.18	11.90	81.67	4.68	4.00	32.31	22.59	30.08	5.61
	WYGL0112	2A2	11	45	18.0	53.0	28.9	25.4	74.6	4.24	1.01	0.04	0.10	5.30	1.51	6.92	12.20	44.14	4.37	3.73	34.84	29.46	15.46	3.73
Humic Cryaquept	WYGL0113	2AC	45	59	17.8	42.6	39.7	29.3	70.5	2.95	0.77	0.03	0.07	6.80	2.20	9.01	12.83	29.78	4.32	3.70	34.49	30.68	11.07	1.92
	WYGL0114	2C	58	95	36.7	26.9	36.4	57.7	42.3	2.46	0.71	0.04	0.06	4.10	1.57	5.67	8.94	36.60	4.32	3.70	23.79	20.52	13.76	1.05
WYGL012	WYGL0121	Oi & Oa	4	0	—	—	—	—	—	30.30	3.07	0.02	0.46	0.04	0.31	0.35	34.21	98.97	4.70	4.20	76.68	42.82	44.16	19.63
	WYGL0122	B	0	19	37.9	29.4	32.8	56.3	43.7	12.14	3.29	0.02	0.15	5.43	0.91	6.34	21.93	71.10	3.89	3.44	38.47	22.88	40.53	3.48
Dystric Cryochrept	WYGL0123	BC	19	33	32.5	36.2	21.2	47.3	52.7	10.57	5.27	0.01	0.03	18.77	2.76	21.53	37.42	42.46	3.89	3.30	47.97	32.08	33.13	0.97
	WYGL0124	C	33	55	40.3	28.1	31.6	58.9	41.1	11.89	6.84	0.03	0.03	19.53	4.69	24.22	43.02	43.69	3.89	3.29	34.80	16.01	54.00	0.49
	WYGL0125	Cr	55	72	32.0	28.0	40.1	53.3	46.7	13.93	8.02	0.01	0.06	21.79	2.00	23.79	45.81	48.07	3.99	3.31	57.10	35.08	38.56	0.21
	WYGL0126*	C	33	55	43.6	27.5	28.9	61.3	38.7	9.45	5.10	0.00	0.03	16.70	2.43	19.13	33.72	43.26	3.90	3.30	40.13	25.54	36.53	0.45
WYGL013	WYGL0131	Oe	13	0	—	—	—	—	—	14.23	2.90	0.06	0.21	0.27	0.32	0.59	17.99	96.71	4.83	4.32	48.31	30.92	36.01	14.30
Histic Cryaquept	WYGL0132	C1	0	36	55.9	24.5	19.7	69.6	30.4	3.68	0.90	0.03	0.07	1.16	0.47	1.64	6.32	74.04	4.50	3.91	15.10	10.42	30.98	1.94
WYGL014	WYGL0141	Oa	5	0	—	—	—	—	—	13.37	2.49	0.21	0.52	3.31	1.70	5.01	21.59	76.79	3.73	3.40	75.28	58.70	22.03	20.72
Distric Cryochrept	WYGL0142	B	0	32	23.0	44.1	32.9	34.3	65.7	0.97	0.17	0.07	0.05	7.45	2.70	10.15	11.41	11.08	3.71	3.42	32.34	31.08	3.91	3.31
	WYGL0143	BC	32	74	25.4	41.8	32.7	37.8	62.2	0.73	0.13	0.00	0.05	7.40	1.13	8.54	9.46	9.75	3.90	3.56	26.55	25.63	3.47	2.59
WYGL015	WYGL0151	A	0	7	32.3	45.6	22.1	41.4	58.6	25.15	3.45	0.05	0.53	0.04	0.06	0.10	29.28	99.65	4.90	4.61	43.35	14.17	67.32	4.89
	WYGL0152	2BA	7	15	19.9	49.7	30.3	28.6	71.4	6.34	1.30	0.09	0.09	4.09	0.03	4.12	11.95	65.50	4.20	3.82	22.23	14.41	35.19	1.76
Distric Cryochrept	WYGL0153	2Bw	15	33	19.5	47.9	32.6	28.9	71.1	1.28	0.36	0.05	0.05	6.36	1.08	7.44	9.18	18.94	4.00	3.59	19.49	17.75	8.92	0.96
	WYGL0154	2BC	33	55	21.8	49.8	28.3	30.5	69.5	0.28	0.26	0.03	0.02	7.71	0.30	8.01	8.60	6.90	3.97	3.55	19.99	19.39	2.97	0.71
	WYGL0155	2CB	55	83	24.4	49.7	26.2	32.6	67.4	0.94	0.36	0.05	0.03	6.02	0.61	6.64	8.01	17.17	4.00	3.62	17.64	16.26	7.80	0.55
	WYGL0156	3C	83	108	33.9	42.2	23.9	44.5	55.5	0.37	0.18	0.04	0.07	4.84	0.00	4.74	5.39	12.10	4.03	3.72	12.73	12.08	5.12	0.58
WYGL016	WYGL0161	Oi & Oa	4	0	—	—	—	—	—	44.38	2.64	0.21	0.78	1.58	0.98	2.56	50.58	94.94	3.62	3.39	112.72	64.70	42.60	>24.00
	WYGL0162	E	0	12	20.6	44.8	34.6	31.5	68.5	1.70	0.35	0.11	0.18	9.19	1.86	11.05	13.38	17.42	3.85	3.09	28.10	25.77	8.30	2.75
Typic Cryoboralf	WYGL0163	EB	12	33	20.8	42.6	36.6	32.8	67.2	0.98	0.27	0.04	0.13	10.03	1.08	11.10	12.52	11.33	3.51	3.20	26.18	24.76	5.42	2.40
	WYGL0164	BE	33	47	15.9	43.0	41.1	27.0	73.0	0.85	0.27	0.03	0.12	12.02	0.64	12.66	13.92	9.08	3.49	3.20	28.72	27.45	4.40	1.88
	WYGL0165	Bt	47	68	39.7	32.1	28.2	55.3	44.7	0.00	0.13	0.04	0.05	2.63	4.27	6.90	7.11	3.04	3.45	3.30	17.28	17.06	1.25	1.35
	WYGL0166	BC	68	102	42.6	29.6	27.8	59.0	41.0	0.00	0.06	0.02	0.03	2.96	0.34	3.30	3.42	3.48	3.60	3.41	10.37	10.25	1.15	0.51
LOST LAKE WATERSHED																								
Ochrept	WYLL0011	A	0	8	44.4	31.8	23.8	58.3	41.7	10.73	1.84	0.06	0.23	0.03	0.13	0.17	13.03	98.72	4.9	4.65	21.27	8.41	60.45	5.01
	WYLL0012	Bw	8	23	41	35.5	23.5	53.6	46.4	5.59	1.27	0.07	0.05	0.16	0.16	0.32	7.3	95.66	4.68	4.35	11.79	4.81	59.2	1.18
Umbrept	WYLL0021	A	0	11	62.9	17.4	19.6	78.3	21.7	1.32	0.3	0.03	0.13	2.79	1.31	4.1	5.9	30.4	3.82	3.5	22.31	20.51	8.04	5.95
	WYLL0022	AB	11	27	58.9	19.5	21.7	75.1	24.9	0.47	0.1	0.03	0.08	3.05	1.14	4.19	4.87	13.98	3.83	3.59	15.79	15.11	4.31	3.84
	WYLL0023	Bw	27	37	71.3	13.3	15.4	84.3	15.7	0.14	0.02	0.04	0.02	1.5	0.66	2.16	2.38	9.31	3.85	3.72	11.01	10.78	2.02	2.03
Umbrept	WYLL0031	A	0	18	30.6	36.7	32.7	45.5	54.5	1.99	0.37	0.11	0.1	7.51	2.04	9.55	12.12	21.14	3.7	3.43	41.87	39.31	6.12	7.94
	WYLL0032	AB	18	35	20.5	40.7	38.8	33.5	66.5	0.64	0.09	0.06	0.04	6.89	2.43	9.31	10.14	8.2	3.73	3.5	36.97	36.14	2.25	4.64
Orthent	WYLL0051	A	0	4	56.8	25.6	17.6	69	31	5.21	1.22	0.15	0.13	—	—	—	106.7	6.28	5.09	4.59	18.98	12.28	35.32	4.41
	WYLL0052	C	4	27	61.1	21.4	17.5	74	26	2.68	0.72	0.04	0.04	—	—	—	103.48	3.37	4.68	4.01	11.39	7.9	30.65	2.17
Orthent	WYLL0061	C	1	31	44.8	37.6	17.5	54.4	45.6	5.13	1.61	0.04	0.08	—	—	—	106.85	6.42	4.9	4.16	13.5	6.64	50.81	—

** — indicates a sample of contrasting material taken from the designated horizon*

Soil Map Units

The map units used in the soil map represent the kinds of soil in the Lost Lake and East and West Glacier Lakes survey areas. A unique set of mapping units was developed for the survey areas and is described in detail. Preceding the name of each map unit is the symbol that identifies that map unit on the map. Each map unit description includes general facts about the soil and a brief description of the soil profile.

The map units on the soil map represent areas on the landscape made up mostly of the soils for which the unit is named. Most of the delineations shown on the map are phases of soil families (Soil Survey Staff 1975; USDA, SCS 1983). No attempt was made to correlate the soils observed during this mapping effort with existing soil series. The soils described as occurring in either survey area were classified to the family level according to the soil classification system described in *Soil Taxonomy* (Soil Survey Staff 1975). The soil family is the lowest taxonomic level recognized in this classification system. Soils of one family discernably differ from soils of other families by texture, mineralogy, reaction class (pH), or soil temperature. The major characteristic separating soil families in the two areas reported here was the texture (relative amounts of sand, silt, and clay) of the fine-earth fraction (< 2mm particle-size fraction). Soils of one family can differ in the texture of the surface layer or in the underlying substratum and in slope, stoniness, or other characteristics that affect their use. On the basis of such differences the family may be divided into phases. The name of a phase commonly indicates a feature that affects use or management and assists in the identification of these soils in the field. For example, Typic Cryoboralfs-Dystric Cryochrepts complex, 5–45% slopes, identifies a particular combination of soil families occurring on a unique range of slopes. The absolute and proportionate extent of each mapping unit in its respective survey is given in table 5.3. Slight overlap of GLEES boundaries occurred when the soil units were mapped. The detailed soil mapping unit descriptions are given in Appendix D.

Most of the map units are made up of two or more dominant kinds of soil. Such map units are called soil complexes, soil associations, or undifferentiated groups. The soil complex was the primary map unit type used in making the soil surveys reported here. A *soil complex* consists of two or more soils that are so intricately mixed or so small in extent that they cannot be shown separately on the soil map. Each map unit includes some of each of the two or more dominant soils, and the pattern and proportion are somewhat similar in all areas.

Most map units include small, scattered areas of soils other than those that appear in the name of the map unit. Some of these soils have properties that differ substantially from those of the dominant soils and thus could significantly affect use and management of the area delineated. These soils are described for each map unit.

Areas that have little or no soil material and support little or no vegetation are called *miscellaneous areas*. These areas are delineated on the soil map. Map units may be composed of one miscellaneous area type, e.g., Rubbleland, nearly level to moderately steep; or they may contain more than one type of area, e.g., Rubbleland-Rock Outcrop complex, steep to extremely steep. Miscellaneous areas may also be included with soil types in naming the dominant components of a map unit, e.g., Rock Outcrop, quartzite-Dystric Cryochrepts-Lithic Cryochrepts complex, 15–45% slopes. In the latter example a phase of the miscellaneous area has been recognized.

Table 5.3.—Map units and their extents within the GLEES soil survey area. Total area reflects area of soil survey rather than area of GLEES listed in Chapter 1.

Map Symbol	Mapping unit name	Total area (hectares)	Percent of area
1	Typic Cryoboralfs-Dystric Cryochrepts complex, 5-45% slopes	8.1	5
2	Typic Cryoboralfs complex, 5–20% slopes	4.9	3
3	Dystric Cryochrepts-Lithic Cryochrepts complex, 5-25% slopes	6.5	4
4	Dystric Cryochrepts complex, 5–25% slopes	4.9	3
5	Dystric Cryochrepts-Rubbleland, quartzite complex, 25-45% slopes	6.5	4
5m	Dystric Cryochrepts-Rubbleland, mafic intrusives complex, 25–45% slopes	4.9	3
6	Typic Cryumbrepts-Dystric Cryochrepts complex, 0–20% slopes	4.9	3
7	Rock Outcrop, quartzite-Dystric Cryochrepts-Lithic Cryochrepts complex, 15–45% slopes	52.1	32
7m	Rock Outcrop, mafic intrusives-Dystric Cryochrepts-Lithic Cryochrepts complex, 15–45% slopes	6.5	4
8	Histic Cryaquepts-Aeric Cryaquepts complex, 0-10% slopes	4.9	3
9	Rubbleland, nearly level to moderately steep	3.3	2
10	Rubbleland-Rock Outcrop complex, steep to extremely steep	29.3	18
11	Permanent Snowfields and Icefields	8.1	5
12	Typic Cryorthents-Rubbleland complex, 45–75% slopes	3.3	2
13	Dystric Cryochrepts-Lithic Cryumbrepts –Rock Outcrop complex, 15–45% slopes	3.3	2
W	Water	11.4	7
	Total	162.9	100

Representative Soil Pedons

In making a soil map, information obtained by observation in one area is extended to similar areas that have not necessarily been directly sampled or even observed. This process depends on careful selection of modal soil pedons that may be used to represent the soil morphological, physical, and chemical characteristics most often observed or most likely to be observed. Representative soil pedons were selected for each of the survey areas. Descriptions of these soil pedons are listed in Appendix E. In addition, physical and chemical characterization data for these soils are also included in table 5.2.

The textural classifications appearing in the pedon descriptions are based on the field hand-texture results and are modified according to the visual estimates of proportionate volumetric quantities of rock fragments. The relative amounts of sand, silt, and clay appearing in the tables of laboratory data were derived by the Bouyoucos hydrometer method as cited. Contrasting particle-size distributions within a soil profile were discerned by calculating relative amounts of sand and silt on a clay-free basis. This aids in overcoming the problem of discerning depositional rather than pedogenic redistribution of particle-size fractions by eliminating the potential confounding arising from differential translocation, accumulation, and loss of clay in the soil profile. Lithologic discontinuities noted in horizon designations for the representative profiles are based on the clay-free distributions of sand and silt.

General Description of the Survey Area

Local alpine glaciation has had a significant effect on the expressed geomorphology of the Snowy Range watersheds. However, the classical U-shaped valleys commonly associated with alpine glaciation do not occur. A main ridge along which Browns Peak (3573 m) and Medicine Bow Peak (3661 m) are located follows a SW-NE trend and forms the northern extent of the watershed. Since no steep-walled valleys existed, permanent snow and ice masses originating in nivation basins along the base of this ridge could have easily coalesced and then flowed in a southerly direction out from the ridge. The nivation basins, or cirques, now are the locations of East Glacier Lake (3282 m), West Glacier Lake (3276 m), and Lost Lake (3332 m). Each lake is located in a separate watershed.

In addition to the glacial influence, the contemporary landscape has been further shaped by nivation and by colluvial and alluvial processes. Evidence for eolian effects in some locations is provided by the clay-free, fine-earth particle size data appearing in table 5.2 and from Rochette (1987).

The bedrock lithologies of these watersheds are similar. They are primarily quartzite with 15–20% amphibolite (mafic) intrusions (Rochette 1987). The quartzite bedrock is extensively fractured in most locations. Soil material fills most or all of the voids formed by these fractures. This results in a prevalence of extremely stony, moderately deep (50–100 cm), and deep soils (> 100 cm) throughout the survey area. Shallow soils (< 50 cm) are usually limited to close association with rock outcrops.

One of the purposes of this soil investigation was to determine the relative potential sensitivity of the soils to acid deposition based on the pH and the base saturation of the soil material. It was felt that bedrock lithology could have a major effect on the sensitivity of these watersheds. Consequently, soil map units were designed to indicate bedrock lithology where appropriate.

The northern portion of the watersheds consists of a steep rock wall and talus slopes. Permanent snow and icefields occur along the upper portions of this wall. Soils in this area, where present, are minimally developed. Most of the soils in these higher elevations are Cryochrepts and Cryorthents. At lower elevations the forest vegetation types are associated with Cryochrepts on raised, well-drained positions. Open grass-sedge meadows are associated with Cryumbrepts. Glacial till occurs between West and East Glacier Lakes and along the SE perimeter of the watershed. Cryoboralfs are associated with these latter sites and generally support forest or krummholz vegetation.

The Cryoboralfs were found to express the lowest pH and base saturation values. Typical pH and base saturation (unbuffered, neutral salt method) profiles for selected Cryoboralfs appear in figure 5.2. Typical base saturation profiles for the Cryochrepts occurring in the watershed appear in figure 5.3. Pedon WYGL012 is a soil developed, at least in part, in residuum from mafic intrusive material. Pedon WYGL006 is a soil developed in colluvium and nivation debris derived from quartzite. The soil represented by Pedon WYGL007 is also developed in predominantly quartzite colluvium and nivation debris; however, mafic intrusives comprised a significant portion of the rock fragments of this soil and indicated a significant influence of mafic material in the soil. This influence probably accounts for the elevated base saturation values comparable with those of the soil developed in mafic intrusive residuum. Representative profiles for the major soil types occurring in the survey areas are compared with respect to base saturation in figure 5.4.

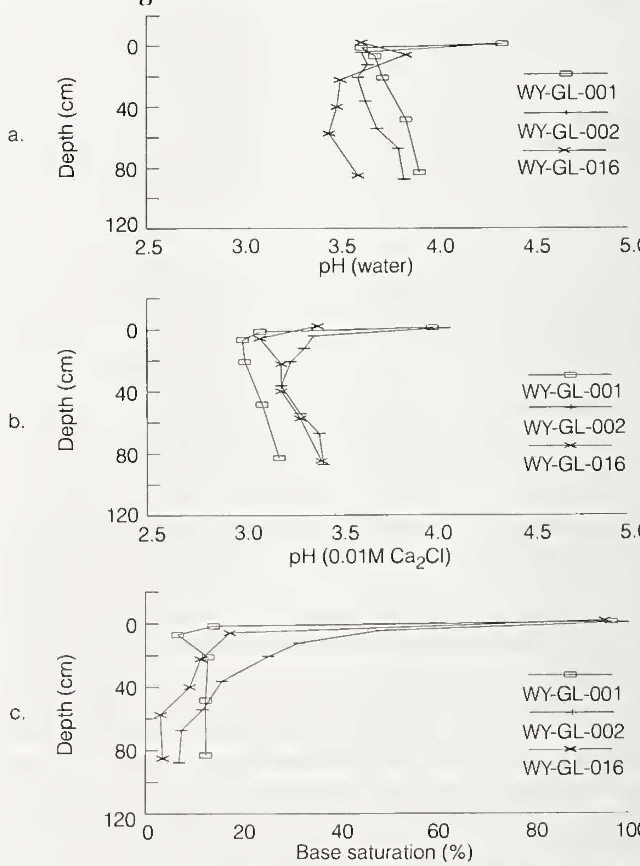


Figure 5.2.—pH and base saturation (neutral salt method) for selected Cryoboralfs in GLEES.

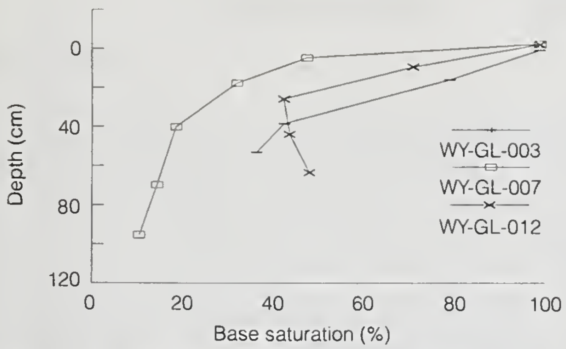


Figure 5.3.—Base saturation (neutral salt method) for selected Cryochrepts in GLEES.

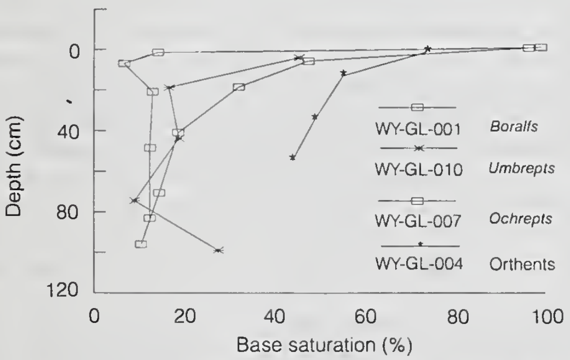


Figure 5.4.—A comparison of base saturation (neutral salt method) for selected pedons of the major soil types occurring in GLEES.

The Cryoboralfs occurring in the GLEES watersheds are generally poorly expressed. Typically only 2% or 3% clay separates the Cryoboralfs and Cryochrepts. Consistent separation of these soils in the field is difficult. Reliance on auxillary characteristics such as color and parent material is of some assistance. The color of the B-horizons is generally more red in the Cryoboralfs than the Cryochrepts. Further, the Cryoboralfs appear to be limited in extent to the distribution of glacial till. Cryochrepts primarily are developed in colluvium and nivation debris.

Three transects were run through the Glacier Lakes watersheds. The purpose of these transects was to observe variations in the pH of surface and near-surface soil material with slope position, elevation, and map unit. Systematic sampling of surface and upper subsoil horizons along these transects was performed for pH determination. Map unit, soil classification, horizon designation and depths, elevation, and slope data were recorded at each sampling site. These data appear in table 5.1. The data indicate that, in general, pH is reasonably constant for like horizon for similar soils within and between map units. Variations in pH occur between dissimilar soils regardless of map unit, slope, or elevation.

References

Arberg, P.A. (project officer). 1985. Statement of work, National Acid Deposition Soil Survey, chemical and physical characterization of soils. EPA contract WA–85-J923. Las Vegas, NV: Environmental Monitoring Systems Laboratory, Office of Research and Development, U.S. Environmental Protection Agency.

Day, P.R. 1965. Particle fractionation and particle-size analysis. In: Black, C.A. et al., eds. Methods of soil analysis, part 1. Agronomy. Madison, WI: American Agronomy Society: 545–567.

Rochette, E.A. 1987. Chemical weathering in the West Glacier Lake drainage basin, Snowy Range, Wyoming: Implications for future acid deposition. Laramie, WY: University of Wyoming. M.S. thesis. 138 p.

Snyder, J.D.; Trofymow, J.A. 1984. A rapid accurate wet oxidation diffusion procedure for determining organic and inorganic carbon in plant and soil samples. Communications in Soil Science and Plant Analysis. 15(5): 587–597.

U.S. Department of Agriculture, Soil Survey Staff. 1975. Soil Taxonomy. In: Agricultural Handbook 436. Washington, D.C: 754 p.

U.S. Department of Agriculture, Soil Conservation Service. 1981. Soil Survey Manual, Chap. 4. [Working Draft] SCS contract 430-V-SSM. Washington, D.C.

U.S. Department of Agriculture, Soil Conservation Service. 1983. Soil Survey Manual, Chap. 3. [Working Draft]. SCS contract 430-V-SSM. Washington, D.C.

U.S. Department of Agriculture, Soil Conservation Service. 1984. Soil Survey Manual, Chap. 2. [Working Draft] SCS contract 430-V-SSM. Washington, D.C.

6. AQUATICS

F.A. Vertucci
EG&G Rocky Flats, Golden Colorado
and
M.A. Conrad
Centennial, Wyoming

Within the GLEES boundary there are three alpine lakes and several streams and ponds. The selection of GLEES as a research site for investigating of the effects of chemical and physical climate change was in part based on the accessibility of these low alkalinity "sensitive" aquatic ecosystems. This chapter provides a brief description of the physical, chemical, and biological characteristics of the GLEES aquatic ecosystems.

Physical Limnology

Lake Morphometry

The lakes at GLEES were formed during the last glacial episode, are no more than 10,000 years old, and were probably formed by ice scour and moraine deposition. Bathymetric maps (figs. 6.1–6.3) were compiled in August of 1987 using a Leitz "Total Station Instrument" to map the location of each lake shoreline and points on each lake surface where depth was measured with either a weighted line or an acoustic depth sounder. Depth was measured with an accuracy of about +25 cm and coordinate locations were very precise (+20cm). Map areas of each iso-depth were digitized using a Numonics series 1200 electronic planimeter.

A summary of lake morphometry and the depth area and volume data are listed in table 6.1. East and West Glacier lakes have similar surface areas and volumes while Lost Lake is slightly more than twice as large. The mean depth of each lake (surface area/volume) is similar and less than 1.5 meters. Lake relative depth (maximum depth/surface area) of East and West Glacier Lakes is about half the relative depth of Lost Lake reflecting the greater maximum depth of Lost Lake (25 m). The shoreline development of each lake (length of shoreline/[$2\left(\sqrt{\pi}\right) * surface\ area$]) expresses the relative potential importance of littoral processes on each lake—the greater the shoreline development, the greater the relative importance of the littoral zone. The GLEES lakes have similarly developed shorelines with Lost Lake being the most sinuous and West Glacier Lake the most circular.

Lake and Stream Hydrology

Parshall flumes were installed on West Glacier Lake outlet in 1986 and on East Glacier Lake outlet and Meadow and Cascade Creeks in 1987. No flume has been installed on Lost Lake because of the decision to concentrate initial studies at East and West Glacier Lakes. Flow is measured continuously; data are averaged to estimate daily flow. In 1988 stream flow began at the onset of snowmelt, May 24 (Julian date 145), and continued in Meadow Creek, Cascade Creek, and West Glacier Lake outlet until about October 26 (Julian date 300). East Glacier Lake outlet flow began at about the same time but was not measured until June 18 (Julian date 170) due to problems with locating the flume and measurement errors associated with slush and ice flow in the flume itself. East Glacier Lake outlet flow ceased on August 5 (Julian date 218). During early snowmelt stream and, to a lesser extent, lake outlet flow is dominated by a strong diurnal pattern of flow associated with diurnal temperature fluctuation and snowmelt. Stream and lake outlet flows for 1988 are presented in figures 6.4 and 6.5. Weekly mean flow is also indicated in each figure. Stream flow is generated by snowmelt and is therefore strongly influenced by temperature (fig. 6.4).

Lake Thermal Properties

East and West Glacier Lakes are dimictic lakes that exhibit thermal stratification under the ice in winter but, due to their shallow depth and high wind velocities, rarely exhibit strong thermal stratification in the ice-free seasons. Lost Lake, with its greater depth, is also dimictic and exhibits strong thermal stratification in summer and winter. The fact that Lost Lake develops a thermocline, which divides the lake basin into an epilimnion, metalimnion, and hypolimnion, influences the chemical and biological characteristics of this lake. The temperature isopleths for 1988 are shown in figure 6.6 for East Glacier, West Glacier, and Lost Lakes. Ice cover begins in October, develops a maximum thickness of over 1 meter, and breaks up in early June.

Lake Optical Properties

Lake transparency varies between lakes and seasonally at GLEES. Weekly Secchi depth measurements display these differences (fig. 6.7). Vertical profiles of light extinction are also available for each lake; figure 6.8 provides an example.

Chemical Limnology

Precipitation

The chemistry of the GLEES aquatic ecosystem is strongly influenced by precipitation inputs that are modified by geologic, edaphic, and hydrologic processes. The chemistry of precipitation at GLEES is measured at the NADP site and through measurement of snowpack chemistry. The estimated volume-weighted concentration and deposition of major ions at GLEES is presented in table 6.2.

Snowmelt

The concentration of ions in snowmelt has been measured using various snow lysimeters. However, contamination of snowmelt with groundwater and surface runoff has been evident (Sanders 1988, Rochette et al. 1988). We have also observed contamination. A typical pattern of snowmelt from an uncontaminated site is shown in figure 6.9 for data collected in 1988.

Streams

Stream chemistry at GLEES varies with the relative amount of stream contact with mafic and nonmafic rock (Rochette et al. 1988). The average concentration of stream chemistry, weighted by flow, for the outlet streams at GLEES is presented in table 6.3 for data collected in 1988.

Lake Outlets

Significant differences exist in outlet chemistry concentrations between East and West Glacier Lakes. Figures 6.10 and 6.11 show the concentrations of base cations, acid anions, and alkalinity for the two outlets. Evidence exists for a slight episodic acidification (alkalinity depression) of about 10 to 20 µeq/l and a pH depression of over 0.5 pH units during snowmelt in West Glacier Lake outlet (Vertucci 1988).

Lake Profiles

Differences in thermal stratification and the amount of snow cover during ice cover primarily determine the differences in lake chemistry observed with depth in each GLEES lake. For example, West Glacier Lake develops high concentrations of ions and elevated alkalinity at the bottom of the lake during ice and snow cover (fig. 6.12). East Glacier Lake does not develop a significant snow cover over the ice. Lost Lake, during midsummer stratification, shows a clinograde change in constituent concentration with depth and evidence of hypolimnetic alkalinity generation.

Biological Limnology

The lakes at GLEES are oligotrophic, concentrations of both phosphorous and nitrogen are low, and algal biomass is subsequently low. On an annual basis production may be further limited by the short ice-free season.

Phytoplankton

Beginning in the winter of 1988, integrated water-column phytoplankton species abundance and biomass have been estimated on a monthly or weekly basis for East and West Glacier Lakes, with fewer data collected from Lost Lake. A list of species collected in 1988 is given in Appendix B. Species abundance and composition changes seasonally in each lake. Summaries of seasonal differences in species composition are given in tables 6.4–6.6. Lost Lake, during summer stratification, has evidenced a hypolimnetic peak in phytoplankton abundance. Vertical profiles of *in vivo* fluorescence and phytoplankton abundance at Lost Lake were measured during the summer of 1988. The potential use of deep-dwelling phytoplankton communities are being investigated as early indicators of lake acidification (de Noyelles et al. 1989).

Zooplankton

The GLEES lakes are dominated by only a few zooplankton species, and levels of abundance are low. A list of species identified in 1988 and their relative abundance is presented in table 6.7.

Benthos

A preliminary qualitative survey of the benthos of each lake was conducted in the summer of 1988. The littoral zones of each lake and each stream were sampled by hand-picking and with a triangle net. Ekman grab samples from the deepest point of each lake were also collected. The resulting species list is presented in Appendix C.

Nekton

The fisheries of the GLEES lakes are managed by the Wyoming Game and Fish Department. Each lake has an unnatural, stocked fishery population. The stocking history of each lake is presented in table 6.8.

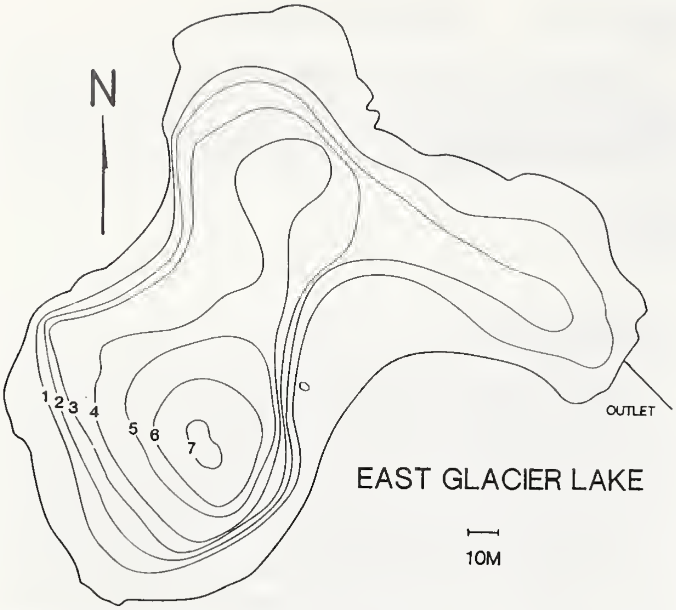


Figure 6.1.—Bathymetric map of East Glacier Lake. Contour numbers are depths in meters.

Figure 6.2.—Bathymetric map of West Glacier Lake. Contour numbers are depths in meters.

References

de Noyelles, F.; Moffett, M.F.; Braun, S.; Vertucci, F.A. 1989. Changes in subepilimnetic phytoplankton as an early response to lake acidification. Bulletin of the Ecological Society of America. 70(2):96.

Rochette, E.A.; Drever, J.I.; Sanders, F.S. 1988. Chemical weathering in the West Glacier Lake drainage basin, Snowy Range, Wyoming: implications for future acid deposition. Contributions to Geology. Laramie: University of Wyoming. 26(1): 29–44.

Sanders, F.S. 1988. Surface water chemistry during snowmelt in a subalpine catchment in southeastern Wyoming: preliminary assessment. Final Report; RMS contract 28-K5-360. 85 p. Available from: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Vertucci, F.A. 1988. Methods of detecting and quantifying lake acidification. In: Poporf, I.G; Goldman, C.R; Loeb, S.L; and Leopold, L.B. eds: Proceedings of the international mountain watershed symposium; June 8–10 1988; Lake Tahoe, CA. Berkeley, CA: University of California Press: 596–602.

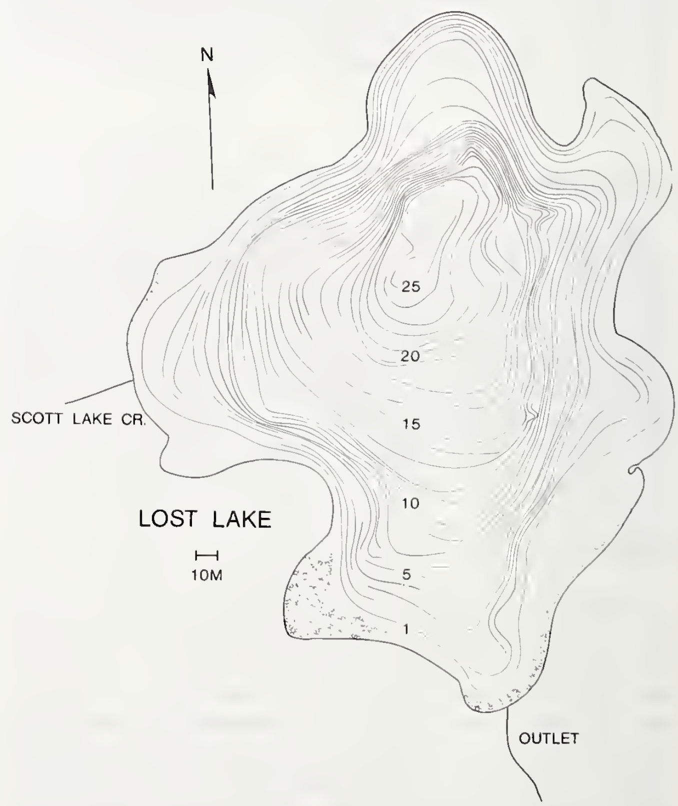


Figure 6.3.—Bathymetric map of Lost Lake. Contour numbers are depths in meters.

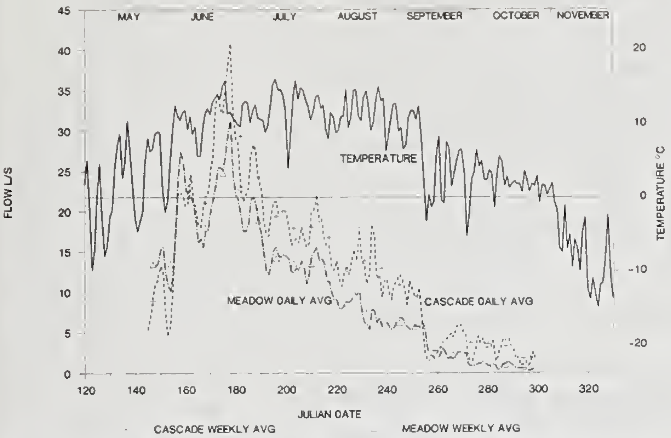


Figure 6.4.—Stream flow and mean daily air temperature for Meadow and Cascade Creeks, 1988.

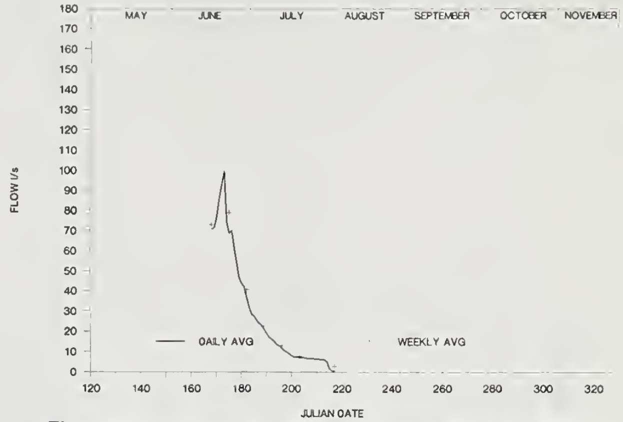


Figure 6.5A.—East Glacier Lake outlet flow for 1988.

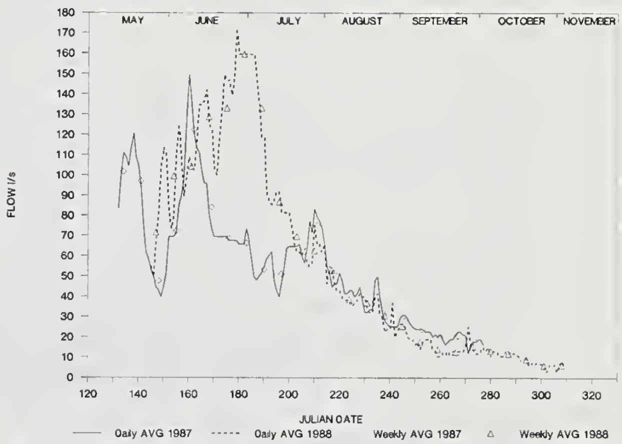


Figure 6.5B.—West Glacier Lake outlet flows for 1987, 1988.

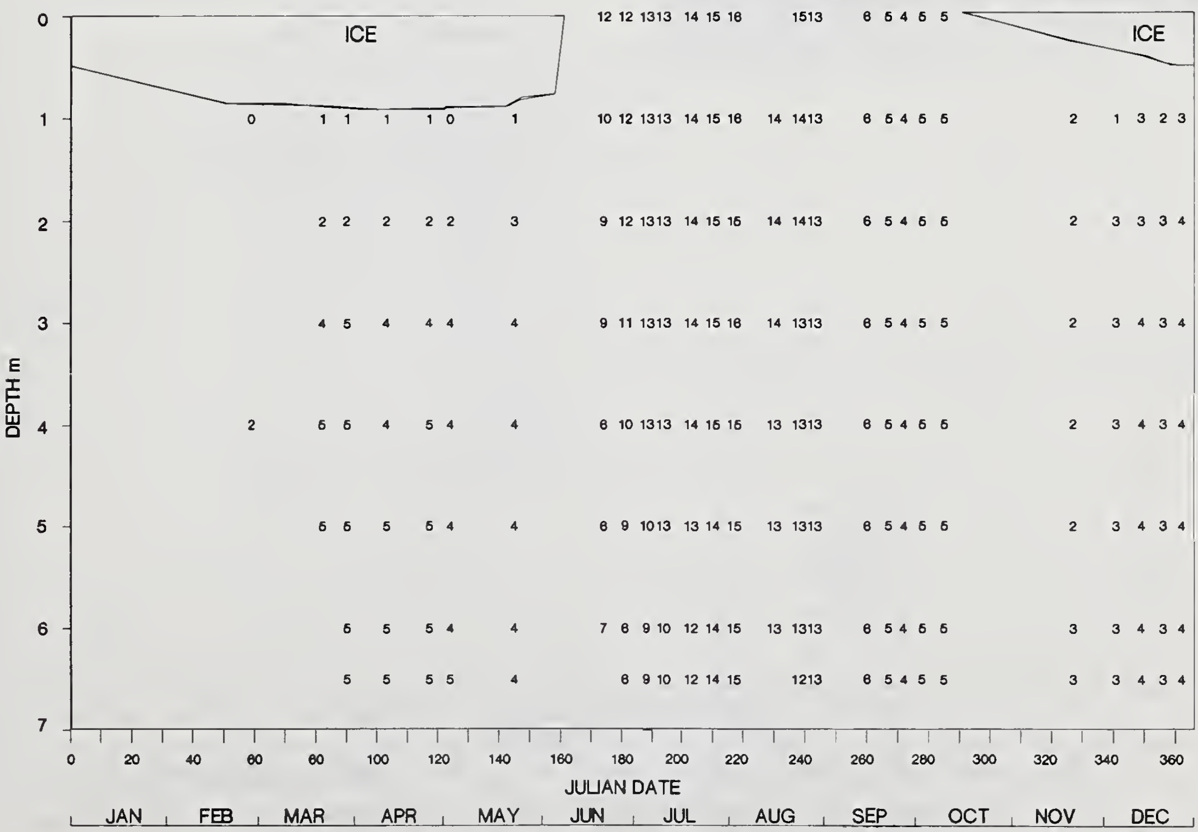


Figure 6.6A.—East Glacier Lake seasonal temperature profile for 1988.

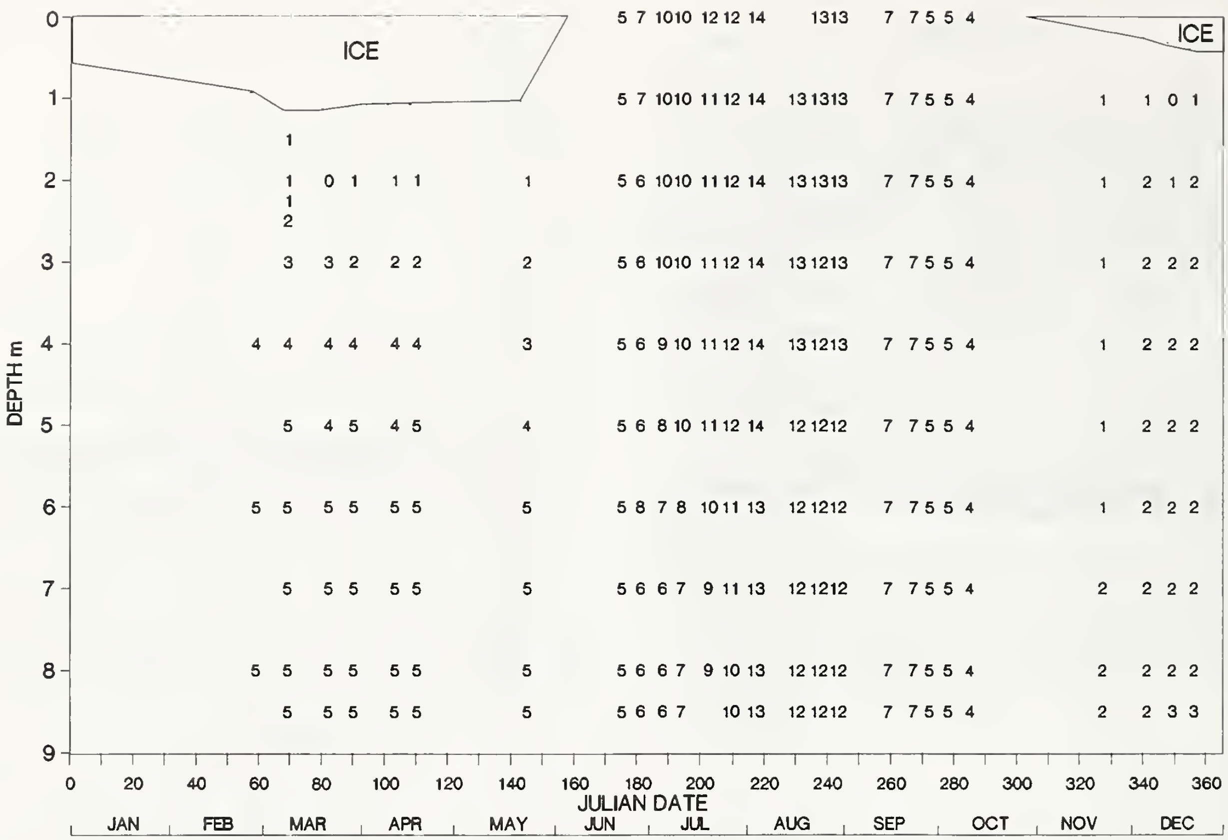


Figure 6.6B.—West Glacier Lake seasonal temperature profile for 1988.

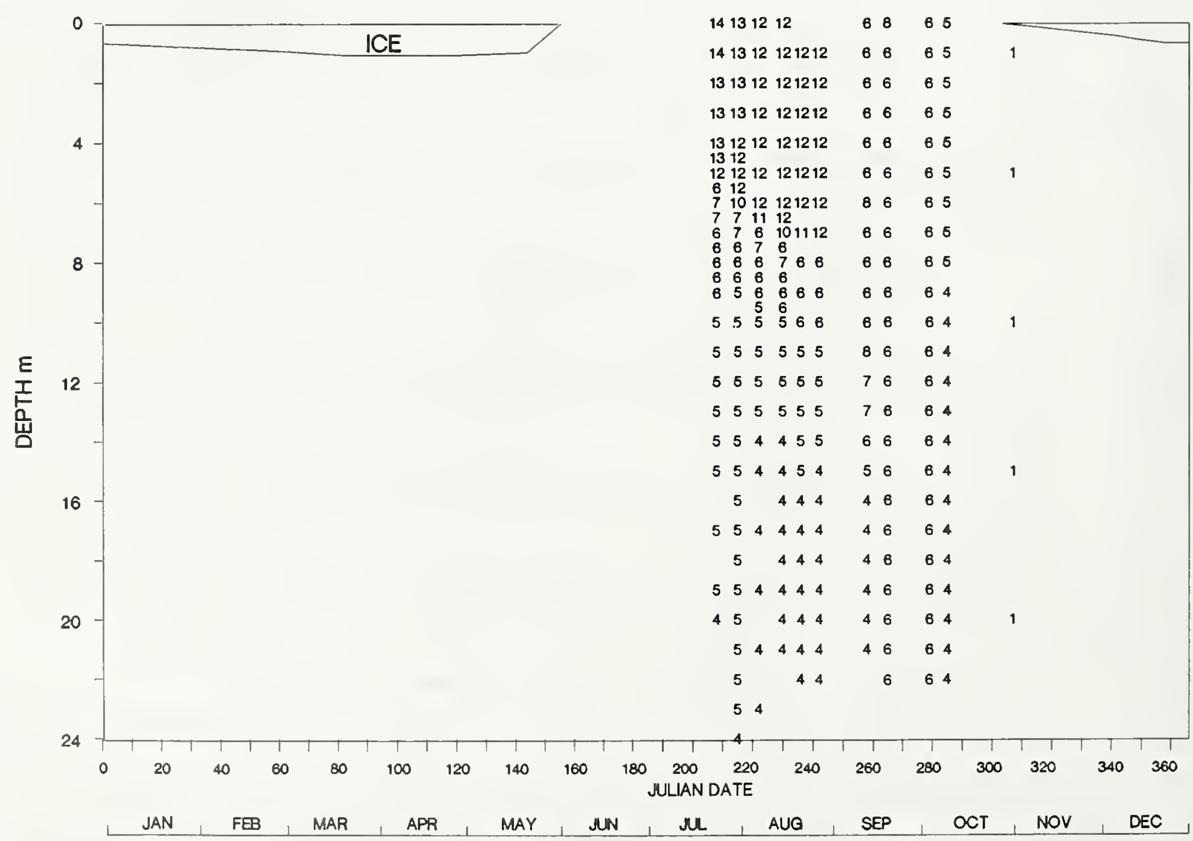


Figure 6.6C.—Lost Lake seasonal temperature profile for 1988.

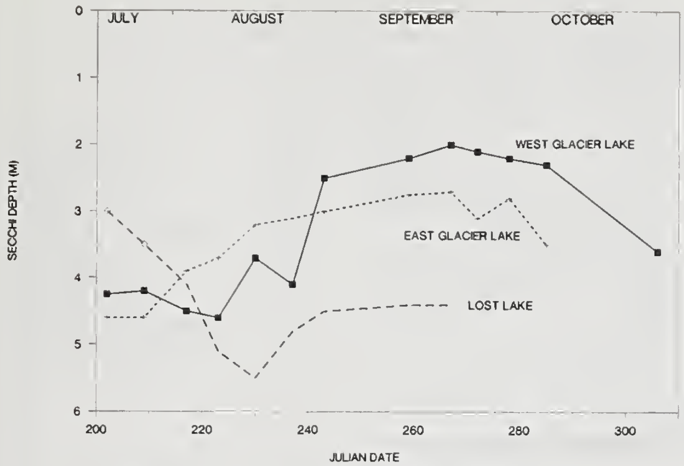


Figure 6.7.—GLEES lakes Secchi depths.

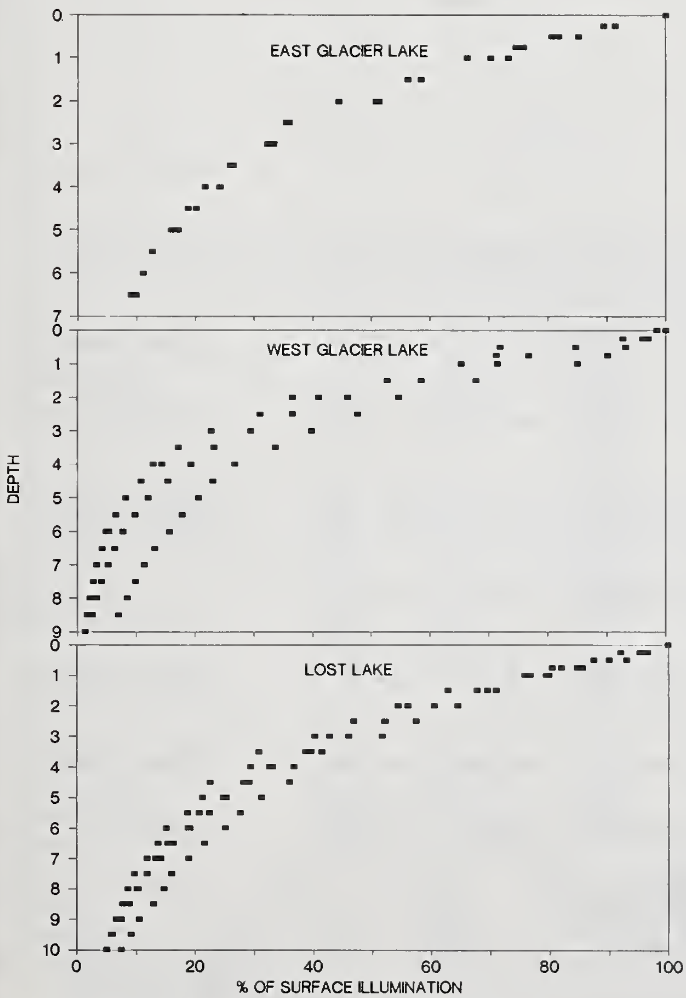


Figure 6.8.—GLEES lakes illumination curves.

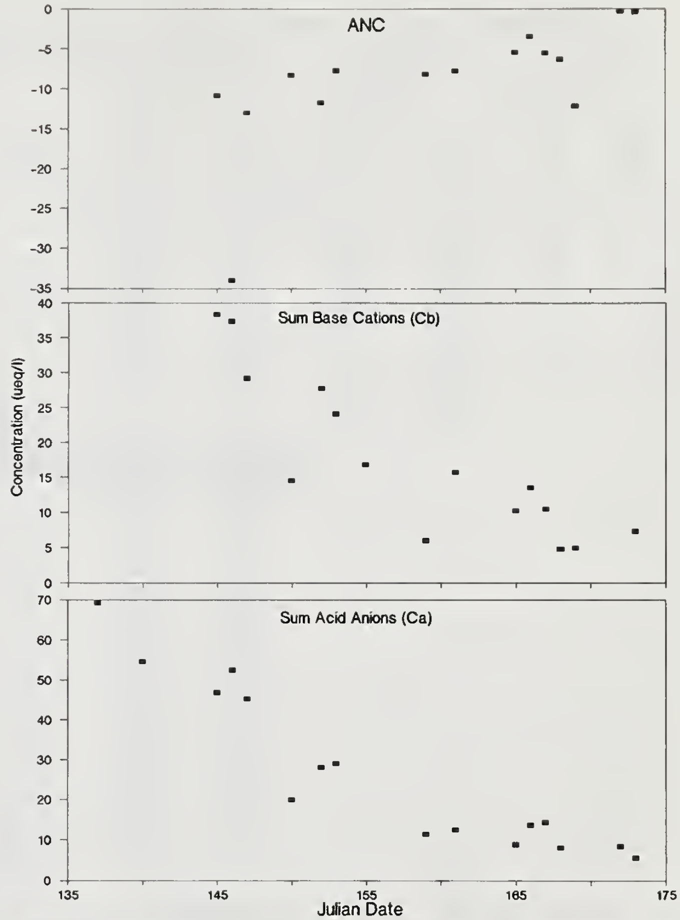


Figure 6.9.—Snowmelt chemistry, East Glacier Lake watershed. The hill snow lysimeter site is located north of East Glacier Lake between East Glacier Lake and Boulder Pond.

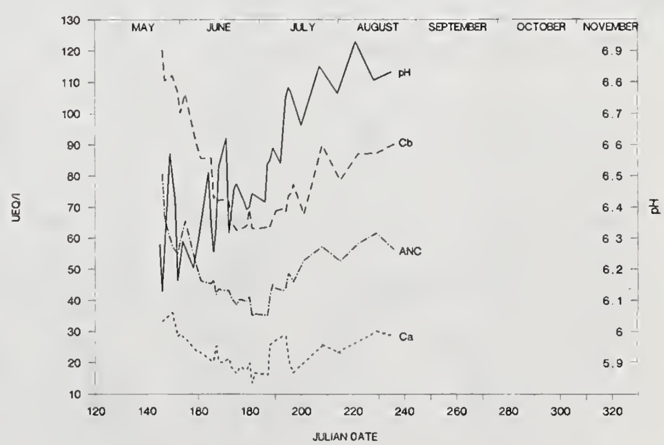


Figure 6.10.—East Glacier lake outlet chemistry 1988.

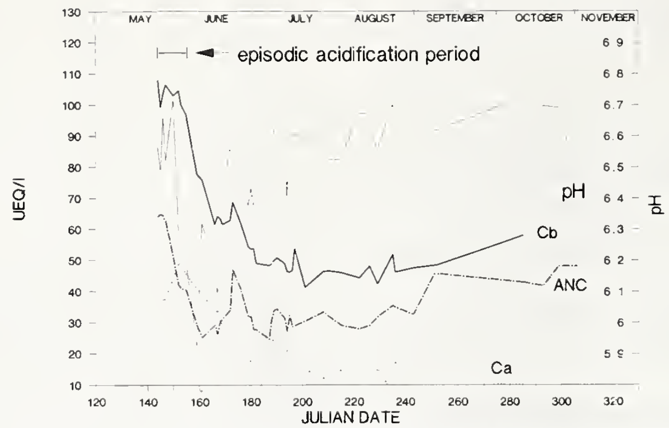


Figure 6.11.—West Glacier lake outlet chemistry exhibiting episodic acidification at snowmelt, 1988.

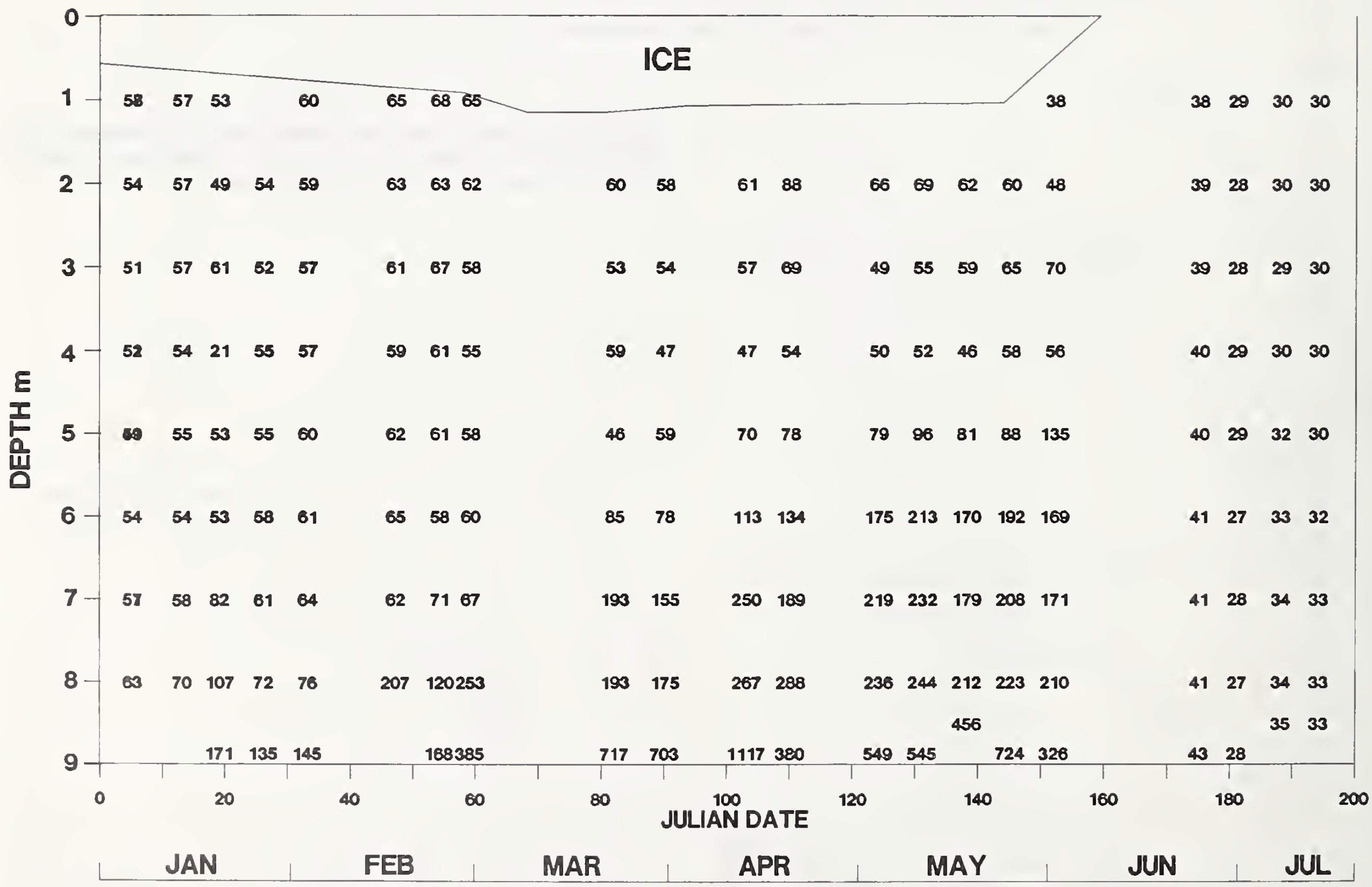


Figure 6.12.—West Glacier lake seasonal alkalinity profile.

Table 6.1A.—Summary of GLEES lakes morphometry.

		Lost	West Glacier	East Glacier
Watershed area	(ha)	51	61	29
Surface area	(m^2)	67086	32869	28805
Surface/watershed		.13	.05	.10
Volume	(m^3)	80111	45162	41345
Mean annual discharge	(m^3)		965 x 10^3	192 x 10^3
Max depth	(m)	25.0	8.5	7.0
Mean depth	(m)	1.19	1.37	1.43
Relative depth	(m)	8.55	4.15	3.66
Shoreline development		1.38	1.21	1.34
Hydrologic residence	(yr)		0.046	0.215

Table 6.1B.—Hypsographic curve data for GLEES lakes.

	Lost		West Glacier		East Glacier	
Depth (m)	Surface area (m^2)	(Volume) (m^3)	Surface area (m^2)	(Volume) (m^3)	Surface area (m^2)	(Volume) (m^3)
0–25	67086	(80111)	32869	(45162)	28805	(41346)
1	11948	(35782)	5620	(17360)	10543	(18925)
2	4918	(8177)	2785	(4121)	13886	(7237)
3	4220	(4564)	3048	(2916)	10378	(3934)
4	4542	(4380)	4739	(3862)	6015	(3928)
5	3008	(3748)	5398	(5065)	2851	(3747)
6	2550	(2776)	3662	(4502)	1441	(2229)
7	2877	(2712)	3214	(3436)	1282	(1345)
8	2970	(2923)	2648	(2926)		
8.5			1323	(974)		
9	2600	(1391)				
10	2068	(1164)				
11	2137	(1051)				
12	1713	(961)				
13	2157	(965)				
14	2327	(1121)				
15	1831	(1037)				
16	2080	(977)				
17	1419	(870)				
18	1936	(835)				
19	2477	(1101)				
20	1059	(859)				
21	1163	(555)				
22	1199	(591)				
23	1003	(550)				
24	1234	(558)				
25	643	(461)				

Table 6.2.—Volume weighted concentration and deposition of major ions in precipitation during the snowpack accumulation period of November 1987 to April 1988 for the East Glacier Lake watershed and the NADP site.

Concentration mg/l	**pH**	**Ca**	**Mg**	**Na**	**K**	**NH_4**	**Cl**	**SO_4**	**NO_3**
Snow survey	+5.21	0.23	0.02	0.26	0.18	0.07	0.26	0.5	0.56
Mean +/- 95% C.I.	5.03	0.18	0.02	0.19	0.14	0.04	0.22	0.46	0.50
	–4.85	0.13	0.02	0.15	0.10	0.01	0.18	0.33	0.44
NADP Nov87-Apr88[1]	5.42	0.14	0.02	0.08	0.06	0.03	0.11	0.48	0.32
Deposition[2] kg/ha	**pH**	**Ca**	**Mg**	**Na**	**K**	**NH_4**	**Cl**	**SO_4**	**NO_3**
Snow survey	+0.10	2.00	0.21	1.97	1.58	0.60	2.22	5.12	4.80
(total)	0.07	1.44	0.16	1.52	1.12	0.32	1.76	3.68	4.00
Mean +/- 95% C.I.	–0.05	0.94	0.11	1.12	0.71	0.08	1.34	2.41	3.27
NADP Nov87-Apr88 (wet only)	0.03	1.12	0.16	0.64	0.48	0.24	0.88	3.84	2.56
Concentration mg/ll	**pH**	**Ca**	**Mg**	**Na**	**K**	**NH_4**	**Cl**	**SO_4**	**NO_3**
Total - Wet Only	+0.07	0.74	0.04	1.19	0.99	0.32	1.19	0.92	1.90
("dry deposition")	0.04	0.32	0.00	0.88	0.64	0.08	0.88	–0.16	1.44
Mean +/- 95% C.I.	–0.02	-0.10	–0.04	0.57	0.29	-0.16	0.57	–1.24	0.98
% Dry of wet	+244	66	24	186	206	132	135	24	74
Deposition	145	29	0	138	133	33	100	– 4	56
Mean +/- 95% C.I.	–75	-9	-24	89	61	-66	65	–32	38

[1] *Precipitation weight average.*
[2] *Calculated using 80 cm H_2O.*

Table 6.3.—Average stream chemistry of GLEES aquatic ecosystems.

Site	pH	Ca	Mg	Na	K	NH_4	Cl	SO_4	NO_3	HCO_3	SiO_2	P	Al
		ueq/l									mg/l		
East Glacier Lake Outlet													
Mean	6.65	46.44	18.07	9.64	2.57	0.32	4.77	12.38	0.91	48.11	1.55	0.01	0.03
STD	0.19	7.01	2.49	2.16	1.21	0.40	3.38	6.77	1.85	7.12	0.16	0.00	0.02
N	89	89	89	89	89	89	89	89	89	89	89	88	89
West Glacier Lake Outlet													
Mean 6.54	31.28	13.12	6.65	2.17	0.59	4.93	13.68	1.83	33.87	1.08	0.01	0.02	
STD	0.14	9.69	3.87	2.32	1.21	1.78	4.36	5.55	3.99	9.08	0.32	0.01	0.02
N	127	127	127	127	127	127	127	127	127	127	126	126	126
Boulder Creek													
Mean	6.46	35.68	14.87	7.34	3.12	0.58	3.52	12.24	5.47	37.93	1.36	0.01	0.03
STD	0.25	13.02	5.63	2.58	1.53	0.69	2.98	5.53	4.12	22.95	0.21	0.01	0.03
N	33	34	34	34	34	34	34	34	34	33	33	32	33
Long Creek													
Mean	6.69	39.91	21.23	10.12	2.43	0.46	1.58	17.83	8.18	47.62	2.73	0.03	0.02
STD	0.11	18.95	10.80	4.94	1.43	0.38	1.33	11.79	5.22	13.92	1.00	0.02	0.01
N	12	14	14	14	14	14	14	14	14	12	13	13	13
Upper Meadow													
Mean	5.78	12.34	4.86	3.65	0.88	0.56	0.93	8.15	7.36	2.85	0.84	0.01	0.03
STD	0.26	7.39	3.33	2.68	0.50	0.30	1.04	6.39	3.43	6.02	0.68	0.01	0.02
N	11	12	12	12	12	12	12	12	12	11	11	12	11
Meadow Creek													
Mean	5.83	20.47	7.33	4.71	1.73	0.29	3.12	12.67	8.39	8.56	0.76	0.01	0.03
STD	0.11	14.66	5.72	3.32	1.69	0.30	3.49	9.90	6.18	6.63	0.39	0.00	0.03
N	64	65	65	65	65	65	65	65	65	64	65	64	65
Upper Cascade													
Mean	5.92	14.24	5.37	2.95	1.00	0.65	1.03	7.52	8.38	4.85	0.84	0.02	0.03
STD	0.13	4.25	1.68	0.93	0.49	0.47	0.63	2.42	3.36	2.51	0.36	0.01	0.02
N	11	12	12	12	12	12	12	12	12	11	12	12	12
Cascade Creek													
Mean	5.84	21.79	7.97	4.66	1.54	0.46	3.31	13.27	9.41	5.55	0.88	0.01	0.03
STD	0.12	17.98	6.82	3.67	1.65	0.47	3.34	11.95	9.88	4.90	0.47	0.00	0.03
N	67	68	68	68	68	68	68	68	68	67	68	68	68
Lost Lake Outlet													
Mean	6.67	65.19	36.80	11.96	6.54	0.21	5.30	22.66	4.52	63.51	2.33	0.01	0.05
STD	0.07	13.30	4.48	1.55	3.52	0.15	7.10	19.49	5.75	7.77	1.84	0.00	0.09
N	7	11	11	11	11	11	11	11	11	7	11	10	11
Lost Lake Inlet													
Mean	6.70	49.62	24.61	9.25	3.42	0.37	2.10	20.28	0.15	49.22	0.84	0.01	0.03
STD	0.04	20.80	7.01	0.55	1.57	0.34	1.15	7.94	0.27	4.31	1.76	0.01	0.07
N	6	10	10	10	10	10	10	10	10	6	10	9	10

Table 6.4.—East Glacier Lake seasonal phytoplankton communities, 1988. (Taxon were identified and density and volume were determined by Richard Dufford, Fort Collins, Colorado.)

		% Composition by		
	Division	Density cell/ml	Volume µm³/ml	Dominant algae
Winter	Bacillariophyta	8	15	*Melosira lirata*
	Chlorophyta	17	6	*Chlamydomonas* spp.
(Feb–April)	Chrysophyta	18	13	*Chrysolykos skujae*
	Cryptophyta	<1	<1	
	Cyanophyta	55	1	*Chroococcus* sp.
	Pyrrophyta	<1	65	*Peridinium willei*
Spring	Bacillariophyta	2	<1	*Rhizosolenia eriensis & Synedra*
	Chlorophyta	55	2	*Chlamydomonas* spp.
(April–May)	Chrysophyta	25	2	*Chrysolykos skujae & Kephyrion*
	Cryptophyta	<1	<1	
	Cyanophyta	17	<1	*Aphanocapsa & Aphanothece*
	Pyrrophyta	1	96	*Peridinium willei*
Early summer	Bacillariophyta	2	1	R.*eriensis* & *Tabellaria fenestrata*
	Chlorophyta	71	2	*Dictyosphaerium elegans*
	Chrysophyta	5	<1	*Dinobryon bavaricum*
(June–July)	Cryptophyta	<1	<1	
	Cyanophyta	21	<1	*Chroococcus* sp.
	Pyrrophyta	1	96	*Peridinium willei*
Summer	Bacillariophyta	2	3	*R.eriensis* & *Synedra incisa*
	Chlorophyta	73	17	*Dictyosphaerium elegans*
(Aug–Sept)	Chrysophyta	7	76	*Dinobryon bavaricum*
	Cryptophyta	<1	<1	
	Cyanophyta	18	<1	*Chroococcus*
	Pyrrophyta	<1	4	*Peridinium inconspicuum*
Fall	Bacillariophyta	<1	5	*R. eriensis* & *Tabellaria*
	Chlorophyta	88	77	*Dictysophaerium elegans*
(Sept–Oct)	Chrysophyta	<1	<1	*Bitrichia* (*Diceras*) *phaseolus*
	Cryptophyta	<1	<1	
	Cyanophyta	11	<1	*Aphanocapsa*
	Pyrrophyta	<1	17	*Peridinium inconspicuum*

Table 6.5.—West Glacier lake seasonal phytoplankton communities, 1988. (Taxon were identified and density and volume were determined by Richard Dufford, Fort Collins, Colorado.)

		% Composition by		
	Division	Density cell/ml	Volume µm³/ml	Dominant algae
Winter	Bacillariophyta	1	10	*Asterionella formosa*
	Chlorophyta	6	45	*Chlamydomonas* spp.
(Feb–April)	Chrysophyta	6	38	*Chrysolykos & Mallomonas* spp.
	Cryptophyta	<1	<1	
	Cyanophyta	87	7	*Anabaena* & *Planklolyngbya subtiiis* (*Lyngbya limnetica*)
Spring	Bacillariophyta	2	27	*Asterionella formosa*
	Chlorophyta	59	38	*Chlorella* & *Chlamydomonas*
(April–May)	Chrysophyta	2	14	*Chrysolykos*
	Cryptophyta	<1	<1	
	Cyanophyta	37	19	*Rhabdogloea ellipsoidea*
	Euglenophyta	<1	2	*Euglena* sp.
Early summer	Bacillariophyta	6	7	*Asterionella formosa*
	Chlorophyta	49	10	*Chlamydomonas*
	Chrysophyta	20	78	*Dinobryon bavaricum*
(June–July)	Cryptophyta	11	5	*Rhodomonas minuta*
	Cyanophyta	14	<1	*Anabaena inaequalis*
Late summer	Bacillariophyta	<1	11	*A.formosa* & *Rhizosolenia eriensis*
	Chlorophyta	48	41	*Dictyosphaerium elegans*
	Chrysophyta	<1	<1	
(Aug–Sept)	Cryptophyta	<1	<1	
	Cyanophyta	51	47	*Anabaena inaequalis*
	Pyrrophyta	<1	<1	*Peridinium inconspicuum*
Fall	Bacillariophyta	2	45	*A.formosa* & *R.eriensis*
	Chlorophyta	2	1	*Chlorella* & *Chlamydomonas*
(Sept–Oct)	Chrysophyta	31	29	*Chrysolykos* & *Mallomonas*
	Cryptophyta	<1	<1	
	Cyanophyta	65	24	*Anabaena inaequalis*
	Pyrrophyta	<1	1	*Peridinium inconspicuum*

Table 6.6.—Lost Lake seasonal phytoplankton communities, 1988. (Taxon were identified and density and volume were determined by Richard Dufford, Fort Collins, Colorado.)

		% Composition by		
	Division	Density cell/ml	Volume µm³/ml	Dominant algae
Summer	Bacillariophyta	28	82	*Asterionella formosa & Tabellaria*
	Chlorophyta	42	16	*Dictyosphaerium elegans*
(July–Aug)	Chrysophyta	<1	<1	
	Cryptophyta	<1	<1	
	Cyanophyta	30	2	*Anabaena inaequalis*
Fall	Bacillariophyta	3	73	*Asterionella formosa & Tabellaria*
	Chlorophyta	4	17	*Dictyosphaerium elegans*
(Sept–Oct)	Chrysophyta	<1	3	*Mallomonas & Kephyrion*
	Cryptophyta	<1	<1	
	Cyanophyta	93	7	*Anabaena inaequalis*
	Pyrrophyta	<1	<1	

Table 6.8.—Fish stocking history of East Glacier, Lost, and West Glacier Lakes (from Wyoming Game and Fish records).

Lake	Date	Species[1]	Number	Number Per #	Length
East Glacier	08/05/38	BKT	4000	—[2]	2"
East Glacier	10/11/57	CUT	2100	300/#	1–3"
East Glacier	08/15/59	CUT	2000	2000/#	1"
East Glacier	08/16/62	CUT	2500	5000/#	.5-1"
East Glacier	07/30/64	CUT	1830	610/#	1–2"
East Glacier	09/24/67	CUT	2750	1100/#	1"
East Glacier	09/18/75	CUT	4000	2000/#	1"
East Glacier	09/06/78	SRC	1680	20/#	—
East Glacier	07/15/80	SRC	990	55/#	—
East Glacier	07/15/82	SRC	500	40/#	—
East Glacier	08/06/84	YSC	1080	90/#	—
East Glacier	08/07/86	YSC	1050	175/#	—
East Glacier	08/04/88	YSC	3500	—	1"
Lost	08/03/33	BKT	12000	—	—
Lost	09/16/37	CUT	30000	—	—
Lost	07/27/38	BKT	12000	—	2"
Lost	07/27/39	BKT	6000	—	2.5"
Lost	07/22/40	BKT	3300	—	2"
Lost	08/28/41	BKT	2240	—	3"
Lost	08/18/42	BKT	4040	—	2–3"
Lost	10/15/51	CUT	3250	650/#	1.5"
Lost	10/07/53	CUT	7200	1800/#	1"
Lost	08/19/60	CUT	4000	2000/#	1"
Lost	06/16/62	CUT	5000	5000/#	.5-1"
Lost	07/30/64	CUT	3660	610/#	1–2"
Lost	09/24/67	CUT	5500	1100/#	1–2"
West Glacier	08/28/47	BKT	4320	254/#	3"
West Glacier	09/29/47	CUT	2760	1104/#	1.5"

[1] *BKT=Brook Trout, CUT=Cutthroat Trout; YSC=Yellowstone Cutthroat, SRC=Snake River Cutthroat.*
[2] *— means no data available.*

Table 6.7.—1988 zooplankton species abundance in East Glacier Lake integrated samples.

					Rotaria				Entomostraca										
										Copepodites State									
Date	Julian Date	Lake	Sample Depth M	Sample Vol L	*Kellicottia longispina*	*Polyarthra dolichopter*	*Keratella* sp.	*Lecane* sp.	Cyclopoid nauplii	I	II	III	IV	V	Total I–V	*Diacyclops thomasi*	*Ceriodaphnia* sp.	*Daphnia ambigua*	Total
3-9-88	69	EGL	0-7	6.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	2.5
3-22-88	82	EGL	0-7	8.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	2.1
3-30-88	90	EGL	0-7	8.0	8.4	0.0	0.0	0.0	1.0	6.1	0.0	0.0	0.0	0.0	6.1	0.0	0.0	0.1	15.6
4-12-88	103	EGL	0-7	8.0	52.5	0.0	0.1	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	65.0
4-19-88	110	EGL	0-7	8.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	7.8	7.8	0.0	0.0	0.0	8.8
5-3-88	124	EGL	0-7	8.0	172.8	7.8	0.0	0.0	4.7	0.0	0.0	3.1	15.8	20.5	39.4	0.1	0.0	3.2	228.0
5-3-88	124	EGL	0-7	8.0	256.3	0.3	0.0	0.0	2.3	0.0	0.0	0.0	8.5	29.9	38.4	0.1	0.0	0.0	307.4
5-3-88	124	EGL	0-7	8.0	123.5	1.8	0.0	0.0	1.9	0.0	0.0	0.0	1.0	2.6	3.6	0.0	0.0	0.0	130.8
5-10-88	131	EGL	0-7	8.0	129.7	27.2	0.0	0.0	50.9	0.0	0.0	0.0	3.3	5.3	8.6	0.0	0.0	0.3	216.7
5-17-88	138	EGL	0-7	8.0	198.4	2.4	0.0	0.0	0.5	0.4	0.5	0.5	0.5	3.1	5.0	0.1	0.0	0.0	206.4
5-24-88	145	EGL	0-7	8.0	119.5	0.1	0.0	0.0	0.3	0.1	0.5	0.1	0.6	2.8	4.1	0.1	0.0	0.1	124.2
6-29-88	181	EGL	0-7	16.0	86.5	0.0	0.0	0.0	57.7	0.2	0.3	0.5	0.3	0.2	1.5	0.2	0.0	0.1	146.0
7-12-88	194	EGL	0-7	16.0	2.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1	5.7	0.2	0.0	8.4
7-20-88	202	EGL	0-7	16.0	95.6	4.8	0.0	0.0	28.8	19.2	33.6	28.8	33.6	19.2	134.4	38.5	3.8	57.7	363.6
7-26-88	208	EGL	0-7	16.0	721.4	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	12.8	12.8	16.3	3.1	0.0	754.2
8-4-88	217	EGL	0-7	10.0	6.1	0.1	0.0	0.0	15.4	0.0	0.1	0.0	0.1	0.8	1.0	70.2	0.0	55.4	148.2
8-4-88	217	EGL	0-7	10.0	10.5	0.0	0.0	0.0	8.3	0.2	0.1	0.1	0.1	2.9	3.4	55.9	0.0	112.8	190.9
8-4-88	217	EGL	0-7	10.0	45.2	0.0	0.0	0.0	17.3	0.0	0.1	0.2	7.7	16.8	24.8	52.3	0.0	92.3	231.9
8-11-88	224	EGL	0-7	10.0	5.3	30.8	0.0	0.0	7.7	0.0	0.0	0.0	0.0	0.0	0.0	27.7	0.0	150.8	222.3
8-17-88	230	EGL	0-7	8.0	19.2	0.0	0.0	0.0	7.8	0.0	0.0	0.0	0.0	0.0	0.0	22.3	0.0	0.8	50.1
8-25-88	238	EGL	0-7	8.0	48.1	28.8	0.0	0.5	38.5	0.0	0.0	0.5	0.5	1.0	2.0	4.7	0.0	0.1	122.7
8-30-88	243	EGL	0-7	8.0	28.8	0.0	0.0	0.0	1.5	1.5	3.4	0.0	2.9	1.6	9.4	46.2	0.0	0.1	86.0
9-16-88	260	EGL	0-7	8.0	0.0	50.0	0.0	0.0	38.5	0.0	0.0	1.6	0.0	1.6	3.2	4.4	0.0	0.5	96.6
9-16-88	260	EGL	0-7	8.0	34.6	43.3	0.0	0.0	9.6	0.0	0.0	0.0	0.0	1.6	1.6	1.6	0.0	0.1	90.8
9-23-88	267	EGL	0-7	18.0	24.3	16.2	0.0	0.0	20.2	0.0	0.0	1.9	0.0	1.9	3.8	1.1	0.0	0.0	65.6
9-28-88	272	EGL	0-7	10.0	15.4	35.4	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	51.8

Table 6.7.—(Continued)

Date	Julian Date	Lake	Sample Depth M	Sample Vol L	Rotaria: Kellicottia longispina	Rotaria: Polyarthra dolichopter	Rotaria: Keratella sp.	Rotaria: Lecane sp.	Entomostraca: Cyclopoid nauplii	Entomostraca: Copepodites State I	Entomostraca: Copepodites State II	Entomostraca: Copepodites State III	Entomostraca: Copepodites State IV	Entomostraca: Copepodites State V	Entomostraca: Total I–V	Entomostraca: Diacyclops thomasi	Entomostraca: Ceriodaphnia sp.	Entomostraca: Daphnia ambigua	Total
10-4-88	278	EGL	0-7	10.0	26.9	76.9	15.4	0.0	46.7	0.0	0.0	0.0	0.0	0.3	0.3	0.4	0.0	0.1	166.7
10-11-88	285	EGL	0-7	10.0	10.2	33.8	3.8	0.1	7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	56.2
3-9-88	69	WGL	0-8	8.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	3.4
3-22-88	82	WGL	0-8	8.0	5.4	0.0	0.0	0.0	4.0	0.5	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	9.9
3-30-88	90	WGL	0-8	8.0	6.5	0.0	0.0	0.0	2.9	1.5	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	10.9
4-12-88	103	WGL	0-8	8.0	4.3	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4
4-19-88	110	WGL	0-8	8.0	38.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	38.6
5-3-88	124	WGL	0-8	8.0	196.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.6	28.4	31.0	0.6	0.0	0.0	228.1
5-3-88	124	WGL	0-8	8.0	92.6	20.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.8	0.0	0.0	0.0	114.8
5-3-88	124	WGL	0-8	8.0	277.9	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	282.0
5-10-88	131	WGL	0-8	8.0	339.6	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.2	0.2	2.0	0.0	0.0	343.2
5-17-88	138	WGL	0-8	8.0	308.8	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.0	309.6
5-24-88	145	WGL	0-8	8.0	398.3	0.0	0.0	0.0	3.1	0.3	0.0	0.0	0.0	1.5	1.8	0.3	0.0	0.0	403.5
6-29-88	181	WGL	0-8	16.0	9.6	0.0	0.0	0.0	19.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	28.9
7-12-88	194	WGL	0-8	16.0	0.0	0.0	0.0	0.0	9.6	4.8	0.0	0.0	14.5	21.6	40.9	0.0	0.1	0.0	50.6
7-20-88	202	WGL	0-8	16.0	177.9	3.2	0.0	0.0	0.0	39.2	77.0	87.6	79.6	115.4	398.8	96.2	0.0	0.3	676.4
7-26-88	208	WGL	0-8	16.0	336.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	57.3	57.3	47.8	0.1	0.0	441.8
8-4-88	217	WGL	0-8	10.0	24.6	0.0	0.0	0.0	10.5	0.0	0.0	0.0	0.0	0.0	0.0	81.6	0.0	8.7	125.4
8-4-88	217	WGL	0-8	10.0	7.8	15.3	0.0	0.0	5.6	0.1	0.2	0.2	0.1	0.3	0.9	123.1	0.0	0.0	152.7
8-4-88	217	WGL	0-8	10.0	61.6	0.0	0.0	0.0	24.6	0.0	0.0	0.2	0.0	15.3	15.5	46.7	0.0	0.1	148.5
8-10-88	223	WGL	0-8	10.0	23.1	61.5	0.0	18.5	35.4	0.0	0.0	0.0	15.3	0.0	15.3	53.8	0.0	0.0	207.6
8-17-88	230	WGL	0-8	10.0	84.6	35.4	0.0	0.0	6.3	0.0	0.0	0.0	10.3	11.9	22.2	115.4	0.0	15.4	279.3
8-24-88	237	WGL	0-8	10.0	135.4	169.3	0.0	0.0	33.8	9.3	8.8	1.5	1.5	0.4	21.5	70.8	0.0	0.0	430.8
8-30-88	243	WGL	0-8	10.0	43.1	7.8	0.0	0.0	0.8	0.0	0.0	2.3	2.3	1.4	6.0	138.5	0.0	0.0	196.2
9-15-88	259	WGL	0-8	8.0	38.5	96.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	57.6	0.0	0.0	192.6
9-15-88	259	WGL	0-8	8.0	115.4	76.9	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	22.3	0.0	0.0	216.5
9-15-88	259	WGL	0-8	8.0	336.6	269.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.3	17.1	0.0	0.0	623.6
9-23-88	267	WGL	0-8	12.0	115.4	51.3	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	167.5
9-23-88	267	WGL	0-8	10.0	138.5	58.3	15.4	0.0	2.4	0.0	0.0	2.4	0.0	0.0	2.4	4.8	0.0	0.0	221.8
9-23-88	267	WGL	0-8	10.0	277.0	53.9	16.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	0.0	0.0	352.4
9-28-88	272	WGL	0-8	10.0	86.2	54.8	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.1	149.9
9-28-88	272	WGL	0-8	10.0	153.9	30.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	189.1
9-28-88	272	WGL	0-8	10.0	148.3	46.2	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	200.2
10-4-88	278	WGL	0-8	10.0	184.7	52.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.4	0.0	0.1	237.6
10-11-88	285	WGL	0-8	10.0	67.3	14.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	88.7
8-2-88	215	LOST	0-5	16.0	118.1	0.0	0.0	0.0	0.0	0.0	0.0	11.4	0.0	11.4	22.8	33.5	0.0	39.3	223.7
8-2-88	215	LOST	9-23	16.0	98.2	136.5	31.5	0.0	41.4	20.9	20.9	10.5	10.5	10.5	73.3	147.0	0.0	0.0	527.9
8-2-88	215	LOST	5-9	16.0	435.8	0.0	0.0	0.0	11.4	0.0	0.0	0.0	0.0	0.0	0.0	50.1	0.0	31.5	528.8
8-9-88	222	LOST	6-10	10	90.2	0.0	0.0	0.0	15.3	1.1	1.8	1.8	7.9	3.3	15.9	7.3	0.0	0.0	128.7
8-9-88	222	LOST	10-23	10	137.6	50.8	0.0	0.0	246.2	7.4	3.9	2.7	8.4	9.6	32.0	85.7	0.0	0.0	552.3
8-9-88	222	LOST	0-6	10	114.0	46.7	0.0	0.0	30.8	0.9	1.3	1.3	3.4	1.2	8.1	4.2	0.0	0.4	204.2
8-16-88	229	LOST	6-10	10.0	32.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.9	69.2	0.0	2.4	105.3
8-16-88	229	LOST	10-23	10.0	30.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.4	18.4	123.1	0.0	0.3	172.5
8-16-88	229	LOST	0-6	10.0	461.7	8.9	1.7	0.0	20.0	3.1	11.2	7.6	18.0	8.3	48.2	76.9	0.0	7.3	624.7
8-23-88	236	LOST	0-6	10.0	15.2	0.1	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	16.8	36.1
8-23-88	236	LOST	10-23	10.0	169.3	0.8	0.3	0.0	107.1	0.0	0.0	0.0	0.0	0.0	0.0	76.9	0.0	30.6	385.0
8-23-88	236	LOST	6-10	10.0	38.4	0.0	0.0	0.0	61.6	0.0	0.0	0.0	0.0	0.2	0.2	24.6	0.0	46.7	171.5
8-29-88	242	LOST	10-23	10.0	15.0	0.2	0.0	0.0	15.3	0.0	0.0	0.0	0.0	0.0	0.0	41.6	0.0	15.3	87.4
8-29-88	242	LOST	7-10	10.0	61.6	0.0	0.0	0.0	30.7	0.0	0.0	0.0	0.0	0.0	0.0	77.0	0.0	92.3	261.6
8-29-88	242	LOST	0-7	10.0	103.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.3	0.0	69.3	204.9
9-14-88	258	LOST	16-21	10.0	0.0	0.0	46.2	0.1	35.4	0.0	0.0	0.0	0.0	0.0	0.0	64.7	0.0	19.9	166.3
9-14-88	258	LOST	0-12	10.0	53.9	30.8	24.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	111.3
9-14-88	258	LOST	0-21	10.0	43.7	60.0	0.0	0.1	38.3	0.0	0.0	0.0	0.0	0.0	0.0	50.8	0.0	6.1	199.0
9-14-88	258	LOST	12-16	10.0	38.2	46.2	11.5	0.0	15.4	0.0	0.0	0.0	0.0	0.0	0.0	56.5	0.0	15.3	183.1
9-21-88	265	LOST	0-25	4.0	38.5	42.3	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	9.0	94.4
9-21-88	265	LOST	0-25	4.0	9.6	15.4	9.4	0.0	11.1	0.0	0.0	0.0	0.0	0.0	0.0	5.5	0.0	8.5	59.5
9-21-88	265	LOST	0-25	4.0	21.5	19.2	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	5.8	0.0	6.5	53.3
10-5-88	279	LOST	0-25	4.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	7.0	8.6
10-11-88	285	LOST	0-25	4.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	4.0	7.1

245

7. METEOROLOGY

D.G. Fox, H.C. Humphries, K.F. Zeller, B.H. Connell, and G.L. Wooldridge
Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado

GLEES is contained within the Snowy Range Observatory. This Observatory consists of many weather stations, precipitation monitors, and stream gages scattered throughout the Snowy Range. These sites have been operated by the Wyoming Water Research Center (WWRC) since 1968. Data from the sites are available from the WWRC and were last summarized by Wesche (1982).

While this long-term record of meteorological information is useful to set the control for GLEES, it is insufficient to characterize meteorological influences on the site. The ecosystems of GLEES are driven by radiation inputs, precipitation inputs, and chemical inputs that are strongly controlled by wind and temperature distributions across the site. Both macro and micro influences of these meteorological quantities are obvious on GLEES. In order to measure representative atmospheric inputs to GLEES, it is necessary to combine a detailed measurement program along with physically based models to expand the spatial detail of the measurements. At this writing, all the techniques to accomplish this are not available. Rather, one objective of the GLEES research will be the refinement of modeling techniques, as well as verification of these techniques using GLEES data.

In this chapter we describe the general climate of GLEES; the atmospheric measurement program and its results through February 1989; and a wind model that has been used to generate a detailed wind pattern over the site.

General Climate

Historical data from the Snowy Range Observatory meteorological stations have been summarized by Wesche (1982). It indicates that mean winter minimum temperatures at Little Brooklyn Lake (fig. 1.3) range from –23°C to –1°C over the years of record. Summer temperatures exhibit means as low as –7°C to a high of 21°C. Freezing temperatures can occur at any time throughout the year, although they are not common in July and August.

Precipitation occurs mostly as snow that can occur anytime during the year, although accumulations are not common in July and August. Summer precipitation occurs primarily as thunderstorms that are common in afternoons. Precipitation measurements at GLEES have been made since 1976, as noted in table 7.1. These measurements are made with Wyoming-shielded collectors, which are standard weighing rain gages surrounded by concentric rings of netting to reduce the deleterious wind effects. Studies have shown that these shields allow collection of approximately 60% of the actual precipitation deposited under the high winds that are common at GLEES (Goodison and Metcalfe 1982).

Winds are very strong and consistent at GLEES as evidenced by the presence of flagged trees and krummholz patterns (see Chapter 2). Wooldridge et al. (1993) used these trees to determine surface wind distributions over the watershed. The Snowy Range Observatory wind measurements are not representative of GLEES because the nearest site is located in a forest canopy in the vicinity of Brooklyn Lakes.

Table 7.1.—Precipitation at the Snowy Range Observatory, Glacier Lakes precipitation collector. Data provided courtesy of University of Wyoming, Wyoming Water Research Center.

	Total monthly precipitation, inches of water											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1976								2.21	0.41	1.55	0.74*	1.89*
1977	1.60*	1.18*	0.77*	2.66*	3.58	0.08	2.54	2.46	0.81	1.34*	1.84*	4.22*
1978	1.29	0.78	2.30	nd	nd	nd	nd	nd	0.00*	1.62	0.92*	nd
1979	0.34*	2.74*	1.79*	2.15*	1.89*	1.58	0.74	4.23	0.91	2.55	5.47	3.41
1980	8.11*	5.77*	7.38	5.48	4.75	0.20	1.13	1.61	2.28	2.97	1.72	2.26
1981	2.33	4.88	4.01	3.02	7.23	0.73	2.04	1.41	1.23	3.60	3.03	7.40*
1982	1.83*	2.81	8.80	3.80*	4.59	2.22	3.16	1.63	3.73	3.71	4.57	5.68
1983	6.38	5.19	9.60	4.70	2.96	3.24	1.91	0.61	0.40	2.25	7.00	7.01
1984	1.87	1.76	3.64	3.34	1.79	1.19	5.20	3.53*	2.76	2.96	4.96	6.30
1985	3.85	2.51	5.69	5.51	2.25	1.27	2.49	0.72	3.22	3.17	9.16	6.24
1986	4.25	7.88	3.35	5.10	2.20	3.72	1.81	1.09	2.53	3.40	3.53	0.36
1987	2.34	1.46	2.24	1.16	2.87	2.27	4.17	1.98	0.46	2.15	2.12*	3.88
1988	6.23	3.58	6.26	1.91	3.69	0.96	0.83	0.84	2.00	0.69	5.15	3.00
1989	2.84	3.99	3.84	2.74								

nd — no data available.
** — includes periods with missing data.*

GLEES Atmospheric Measurements

Meteorological measurements are currently made at the following sites at GLEES:

Brooklyn Lakes meteorological tower (fig. 1.3)

Glacier Lakes meteorological tower (fig. 1.3)

NADP site (fig. 1.3)

Table 7.2 lists the parameters measured at the Glacier Lakes and Brooklyn Lakes sites. At the NADP site, precipitation and net radiation are recorded year round, while wind run and direction and pan evaporation are recorded at ground level during the growing season.

A National Dry Deposition Network (NDDN) monitoring site was established near the Centennial Work Center (fig. 1.2) in 1989, and moved to a site near the Brooklyn meteorological tower in 1991. This site includes a 10 m tower with meteorological and air quality measurements (table 7.3) and filter pack for SO_2, SO_4, NO_3, NO_x, and HNO_3.

Figures 7.1–7.3 present monthly summaries of the data from Glacier Lakes tower for January, March, and August of 1991. The presentation illustrates monthly trends in all parameters. Figures 7.4–7.9 present the same information from the Brooklyn Lakes site. Temperature and winds are measured at 10 m and 30 m heights. Meteorological data are available in the PARADOX database for all months since installation of the systems in 1987.

Table 7.2.—Meteorological monitoring measurements at GLEES.

Sensor:	Temperature	Relative humidity	Wind speed	Wind direction	Pyra	Precip	Wet/dry	Ozone*
Type:	Thermistor	Carbon resistance	Switch	Potentiometer	Silicon photodiode	Weighing	Conductivity	Photometric
Dimensions:	°C	%	m/sec	degrees	watt/m^2	mm	% of time	
Manufacturer:	Fenwal Electronics	Phy-Chem Scientific	MetOne	MetOne	LiCor	Belfort	Campbell Scientific	Thermo Electron
Model:	UUT51J1	PCRC–11	013	023	LI–200s	500mm	231	49
Calibration Schedule:	Biweekly	Biyearly	Biyearly	Biyearly	2 Years	Random	None	Daily
Calibration Method:	Vaisala	Salts	Wind Tunnel	Ohm Meter	Epply	Weights	Unit Gen.	
Sensor Height Glacier Lakes+	20 m	20 m	20 m	20 m	20 m	2 m	10 m	
Brooklyn Lake# Upper/Lower:	10 m/30 m	10 m/30 m	10 m/30 m	10 m/30 m	30 m	2 m	11 m	3 m

** Ozone monitored only at Brooklyn Lake.*
+ Glacier Lakes site elevation 3286 m.
 # Brooklyn Lake site elevation 3182 m.

Table 7.3.—Measurement specifications from ESE, operator of the NDDN (1987).

Measurement	Averaging time	Sampling frequency	Measurement method	Nominal lower quantifiable limit	Manufacturer's precision
Ozone	1 hr	24 hr/day	Ultraviolet photometric	2 ppb	±2 ppb
Windspeed	1 hr	24 hr/day	3-cup anemometer	0.22 m/sec threshold	±0.07 m/sec or ±1%
Wind direction	1 hr	24 hr/day	Wind vane threshold	0.22 m/sec	±2°
Temperature at two levels, (T)	1 hr	24 hr/day	Thermistor in motor-aspirated shield	NA	±0.1°C
Dewpoint	1 hr	24 hr/day	Lithium chloride dew cell	NA	±0.5°C
Solar radiation	1 hr	24 hr/day	Photovoltaic pyranometer	NA	±5% max
Precipitation	1 hr	24 hr/day	Rain gage, weighing type	0.25 mm	±0.25 mm
Wet deposition	1 week	1/week	Wet-dry sampler		
pH			pH electrode	NA	±0.1 pH
volume			Balance	1 cm^3 (1 g)	±1 cm^3 (±1 g)
Conductivity			Conductivity electrode	1 umho/cm	±2%

Note: ° = degrees; hr/day = hours per day; °C = degrees Celsius; mm = millimeter; cm³ = cubic centimeter; m/sec = meters per second; g = gram; ppb = parts per billion; hr = hour; umho/cm = micromhos per centimeter.

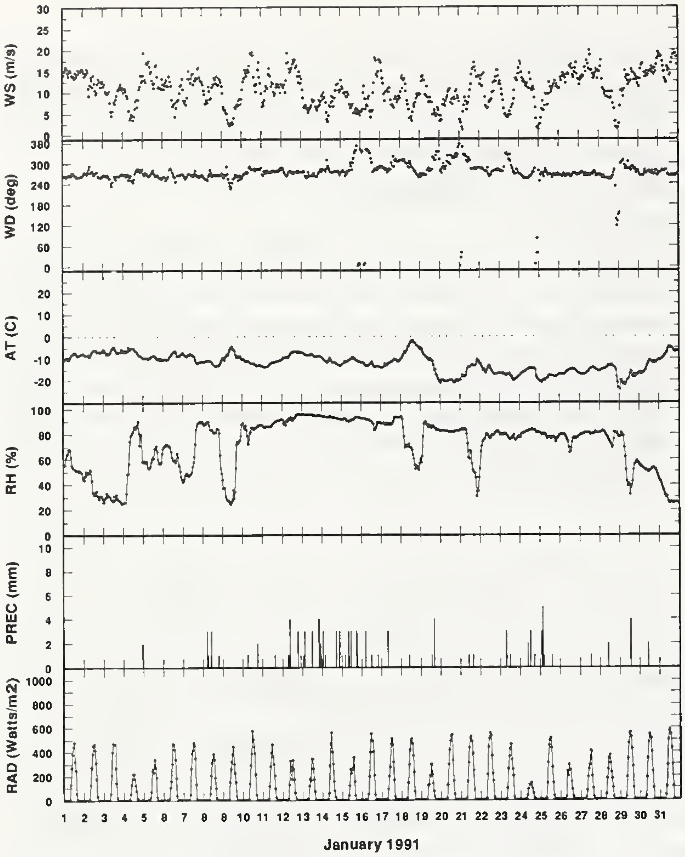


Figure 7.1.—Meteorological time plot, Glacier Lakes, January 1991, where PREC = precipitation, WS = wind speed, WD = wind direction, AT = air temperature

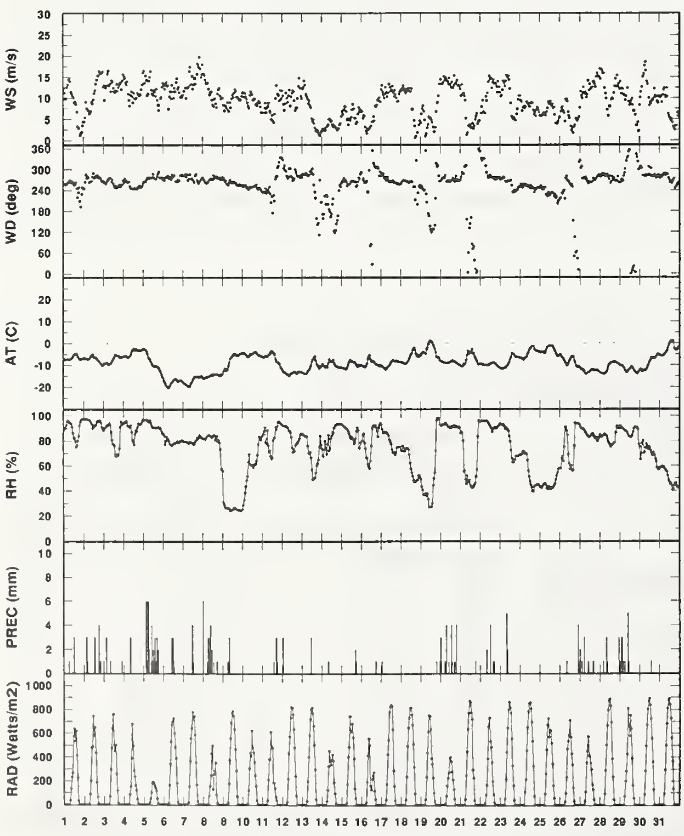


Figure 7.2.—Meteorological time plot, Glacier Lakes, March 1991; same abbreviations as in figure 7.1.

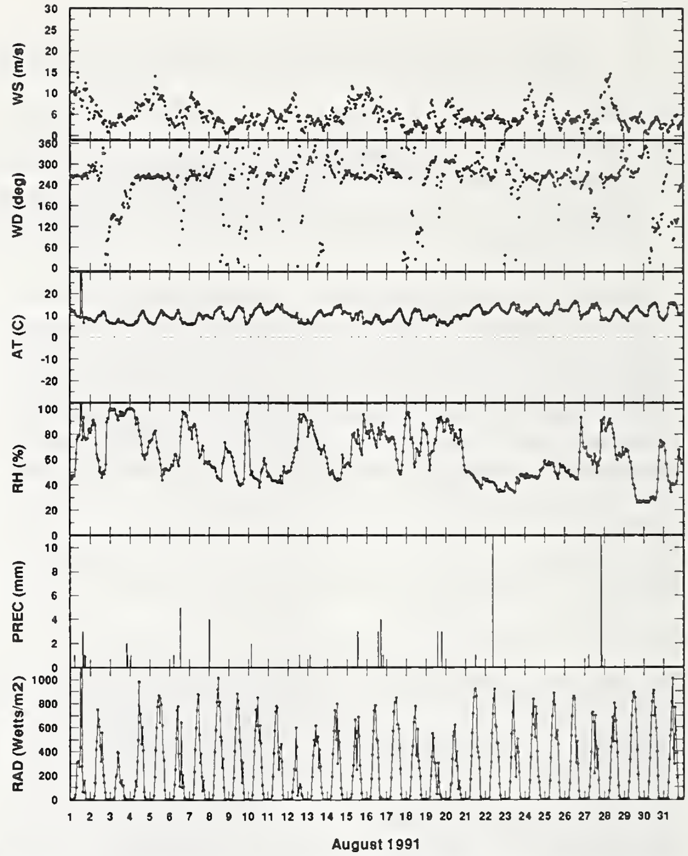


Figure 7.3.—Meteorological time plot, Glacier Lakes, August 1991; same abbreviations as in figure 7.1.

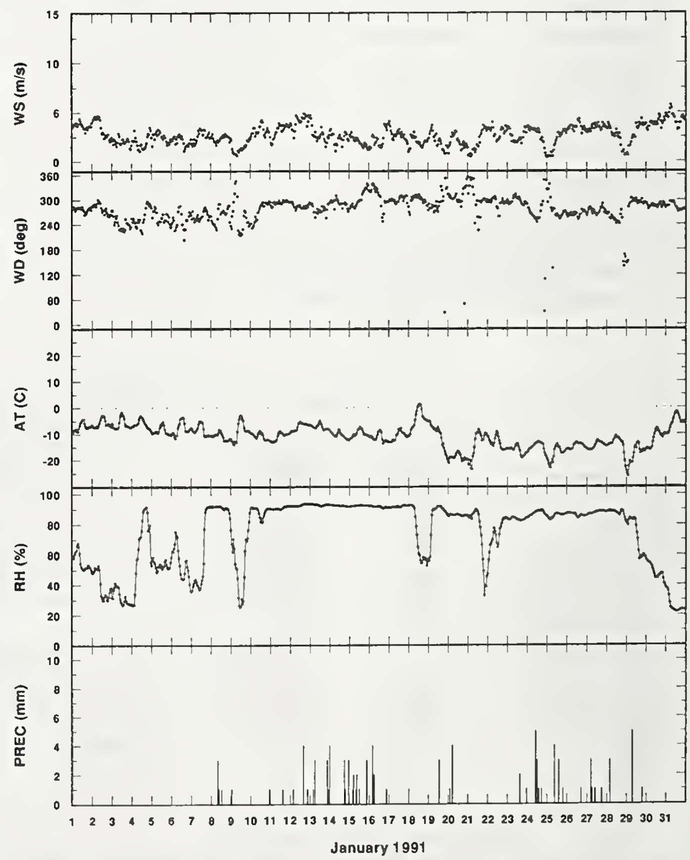


Figure 7.4.—Meteorological time plot, Brooklyn Lakes, lower sensor, January 1991; same abbreviations as in figure 7.1.

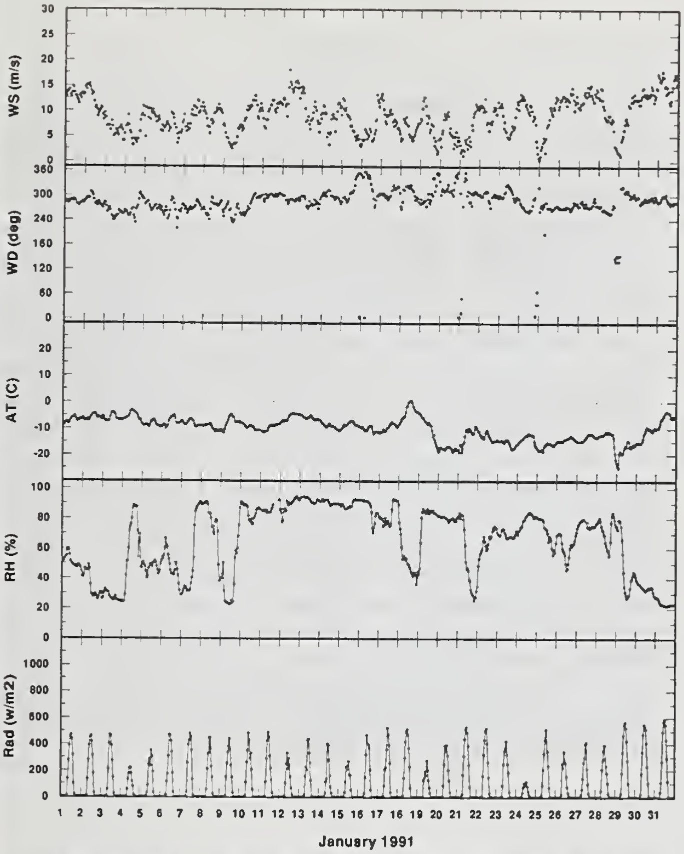


Figure 7.5.—Meteorological time plot, Brooklyn Lakes, upper sensor, January 1991; same abbreviations as in figure 7.1.

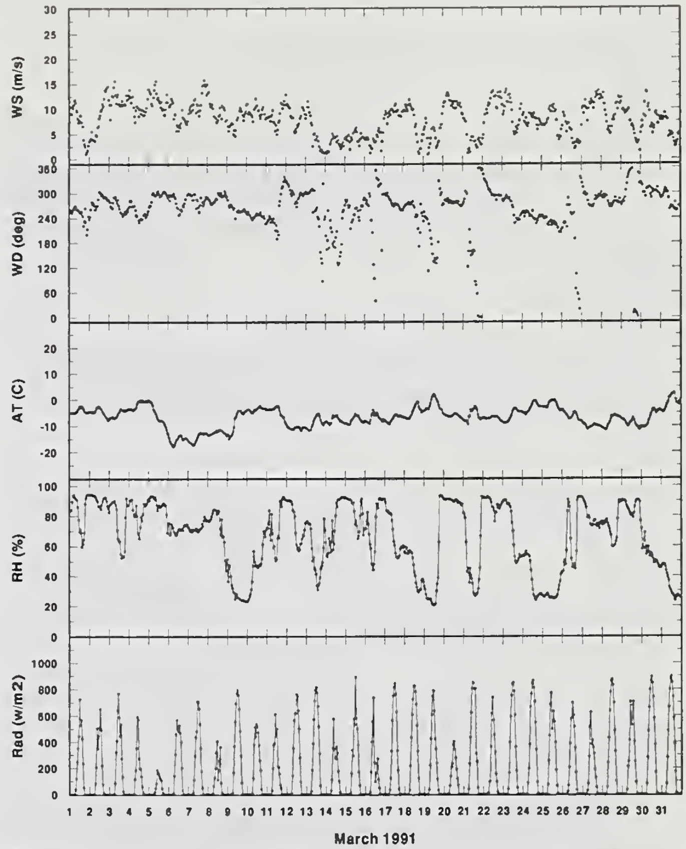


Figure 7.7.—Meteorological time plot, Brooklyn Lakes, upper sensor, March 1991; same abbreviations as in figure 7.1.

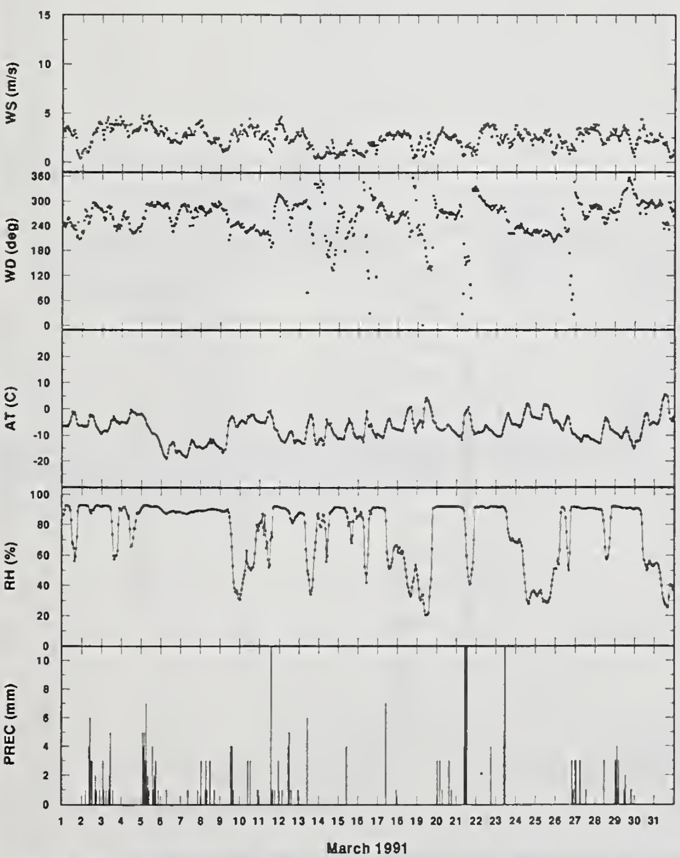


Figure 7.6.—Meteorological time plot, Brooklyn Lakes, lower sensor, March 1991; same abbreviations as in figure 7.1.

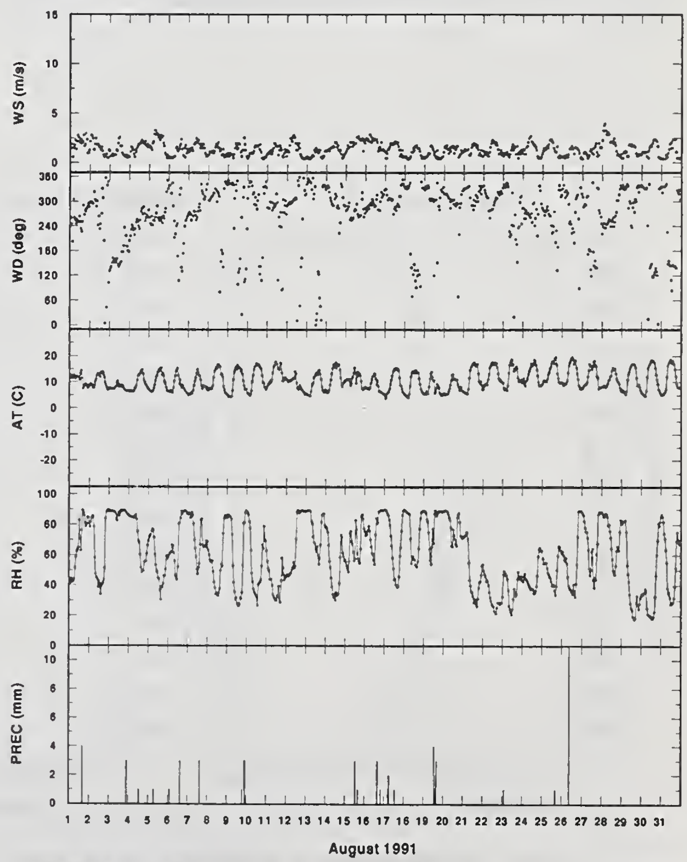


Figure 7.8.—Meteorological time plot, Brooklyn Lakes, lower sensor, August 1991; same abbreviations as in figure 7.1.

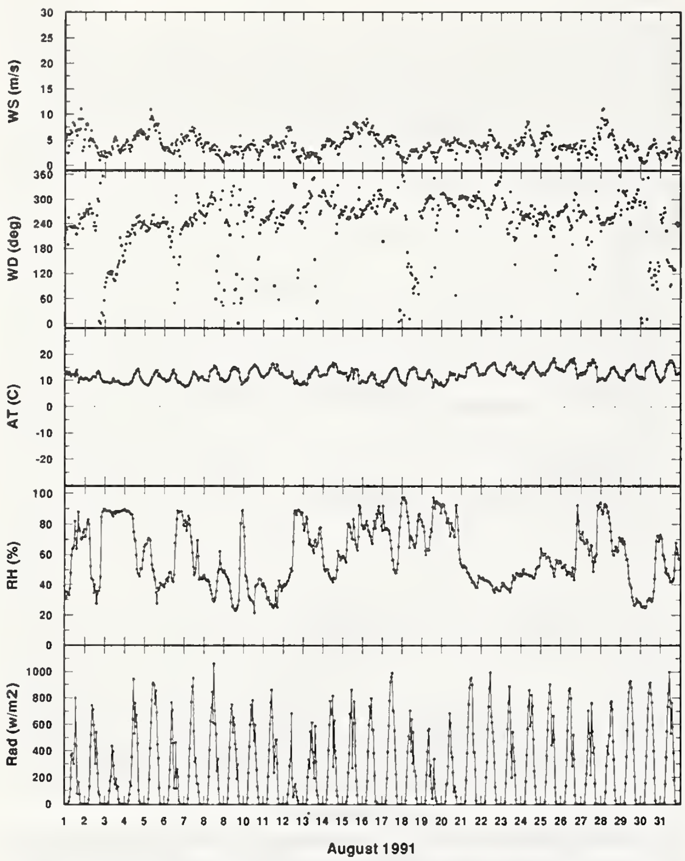


Figure 7.9.—Meteorological time plot, Brooklyn Lakes, upper sensor, August 1991; same abbreviations as in figure 7.1.

Modeling

Even a casual observer at GLEES is struck by the complexity of the wind distribution that directly affects vegetation growth (as evidenced by flagging and lack of regeneration on exposed locations) and indirectly affects the vegetation mosaic through snow distribution.

Since it is impossible to measure all microscale variation, we used a wind model to simulate distributions. NUATMOS is a three-dimensional diagnostic wind model (Ross et al. 1988) and is part of the TAPAS group of models (Fox et al. 1987). NUATMOS requires detailed input information to accurately depict the winds in complex terrain (Connell 1988). In order to provide such detailed input, free-flying constant volume balloons were released at GLEES and tracked by dual theodolites. Figure 7.10 displays an example of the sounding resulting from a balloon release on September 17, 1987. Using such input data, wind distributions for GLEES and the surrounding area were calculated. Figure 7.11 presents an example of results from this model. A vertical cross-section through the field as illustrated in figure 7.11 is shown in figure 7.12. These calculated wind patterns provide an opportunity to study micrometeorological influences on GLEES in detail.

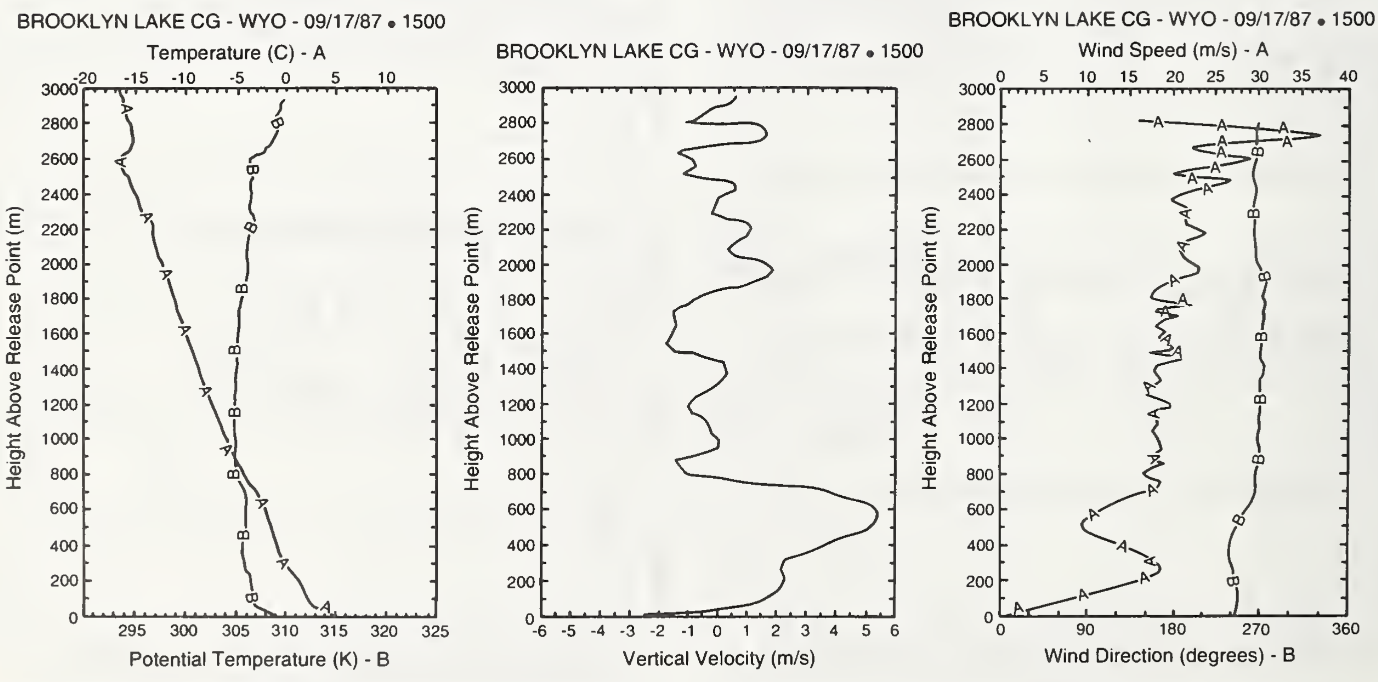


Figure 7.10.—Vertical profile data at Brooklyn Lake campground from sounding on September 17, 1987, at 1500 hours.

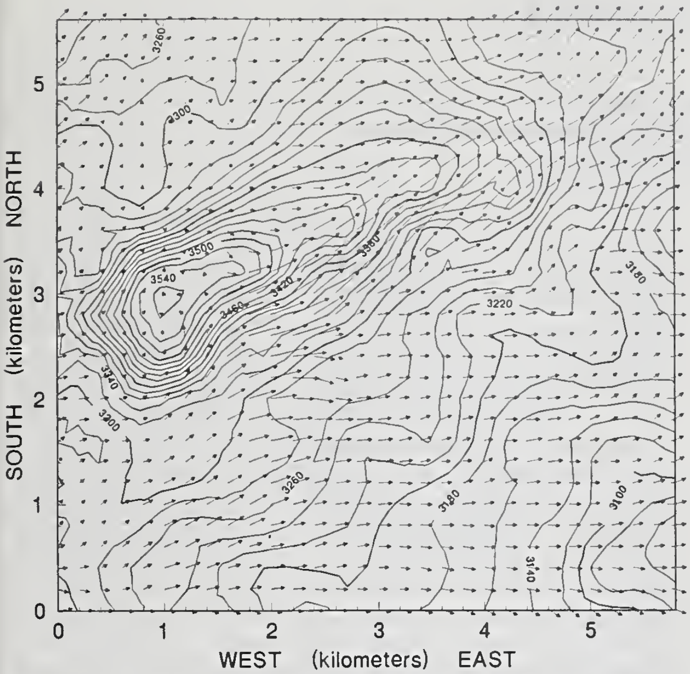


Figure 7.11.—Model output of wind distribution at GLEES and vicinity.

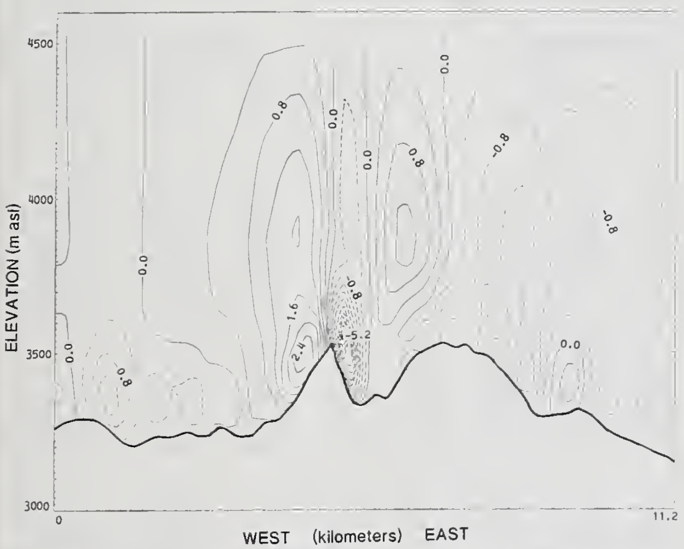


Figure 7.12.—Contours of vertical velocity (cross section through y=34). Solid lines denote positive values; dashed lines denote negative values. Contour increment = 0.4m/s.

References

Connell, B.H. 1988. Evaluation of a 3-D diagnostic wind model: NUATMOS. Fort Collins, CO: Colorado State University. 135 p. M.S. thesis.

Environmental Science and Engineering, Inc. 1987. NDDN measurement specifications. NDDN operating manual.

Fox, D.G.; Ross, D.G.; Dietrich, D.L.; Mussard, D.E.; Riebau, A. 1987. An update on TAPAS and its model components. In: Proceedings of the ninth conference on fire and forest management; 1987 April 21–24; San Diego, CA. Boston: American Meteorological Society: 1–6.

Goodison, B.E.; Metcalfe, J.R. 1982. Canadian snow gauge experiment, recent results. In: Proceedings of the Western Snow Conference: 1982 April 20–23; Reno, NV: 192–195.

Ross, D.G.; Smith, I.N.; Manins, P.C.; Fox, D.G. 1988. Diagnostic wind field modeling for complex terrain: Model development and testing. Journal of Applied Meteorology. 27: 785–796.

Wesche, T.A. 1982. The snowy range observatory: An update and review. Water Resources Series Report 81. Laramie, WY: University of Wyoming, Water Resources Research Institute. 310 p.

Wooldridge, G.I.; Musselman, R.C.; Sommerfeld, R.A.; Fox, D.G.; Connell, B.H. 1993. Mean wind patterns and snow depths in an alpine-subalpine ecosystem as measured by damage to coniferous trees. [Manuscript in preparation].

8. AIR QUALITY

R. C. Musselman
Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado

Air quality is monitored continuously at GLEES. Air pollutants are considered an important component of the atmosphere that can have an effect on terrestrial and aquatic ecosystems. Atmospheric deposition of gases, wet deposition of chemicals in precipitation including snow and rain, and dry deposition of chemicals are all monitored at GLEES. Although GLEES is a relatively remote and unpolluted site, deposition of pollutants can be important. The effects of ozone on native vegetation in alpine and subalpine ecosystems is generally unknown, but relatively high concentrations of ozone have been recorded at GLEES. Wet and dry deposition is important in snowmelt chemistry and subsequent input to aquatic ecosystems at GLEES.

Wet deposition is monitored at the GLEES Snowy Range National Atmospheric Deposition Program (NADP) site on the west shore of West Glacier Lake. The station has been in operation since 1986, and was initially installed and operated by the University of Wyoming. It has been operated by the Rocky Mountain Station since 1990. Wet precipitation is collected every Tuesday at the site and sent to the NADP Central Analytical Laboratory (CAL) in Illinois. Protocols allow collection on Wednesdays if necessary. The Snowy Range site is one of about 200 wet deposition sites in the network. Precipitation is also recorded at the NADP site with a standard Alter-shielded Belfort rain gage. Precipitation collection in winter is low since snow tends to blow out of the buckets used for water chemistry samples. Research on better snow collection methods is being conducted. Weekly data from the Snowy Range NADP site and from the entire network is available from NADP. A summary of data output from the NADP site is listed in table 8.1.

Table 8.1.—Summary data from Snowy Range NADP site, 1987–1991.

			Precipitation-weighted mean concentrations									Totals[1]			
			m/g/Liter												
Year	Dates		Ca	Mg	K	Na	NH_4	NO_3	Cl	SO_4	pH	µS/cm Cond.	c/a Ratio	mL Svol	cm Ppt
Annual															
1986	860422	861230	0.20	0.024	0.021	0.104	0.06	0.51	0.08	0.53	5.27	5.8	1.18	12708.4	65.08
1987	861230	871229	0.20	0.029	0.019	0.149	0.09	0.63	0.13	0.60	5.20	6.6	1.16	22374.6	87.07
1988	871229	890103	0.19	0.025	0.018	0.116	0.05	0.51	0.11	0.72	5.18	6.8	0.99	8575.9	119.48
1989	890103	900102	0.19	0.028	0.013	0.206	0.15	0.77	0.16	0.77	5.67	6.8	0.97	12986.1	126.70
1990	900102	910102	0.19	0.027	0.014	0.089	0.12	0.76	0.13	0.49	5.43	5.8	0.99	15906.7	130.39
1991	910102	911231	0.14	0.018	0.014	0.089	0.09	0.67	0.10	0.51	5.29	6.2	0.94	21802.6	125.05
Winter															
1987	861202	870303	0.15	0.027	0.020	0.219	0.10	0.49	0.18	0.53	5.47	5.7	1.19	1592.2	18.11
1988	871201	880301	0.17	0.028	0.019	0.157	0.02	0.41	0.14	0.53	5.27	5.6	1.14	1203.9	44.36
1989	881129	890228	0.10	0.017	0.007	0.467	0.21	0.81	0.20	0.95	6.14	8.4	1.03	480.3	48.29
1990	891129	900227	0.14	0.025	0.009	0.075	0.07	0.68	0.12	0.46	5.50	5.1	0.82	1333.1	45.37
1991	901204	910226	0.12	0.017	0.007	0.079	0.02	0.51	0.08	0.28	5.45	4.9	0.95	1079.4	34.85
Spring															
1986	860422	860603	0.74	0.060	0.029	0.126	0.01	0.27	0.11	0.66	5.89	7.5	2.36	2172.6	6.07
1987	870303	870602	0.39	0.044	0.030	0.163	0.11	0.96	0.18	0.79	5.10	8.9	1.21	5266.7	21.21
1988	880301	880531	0.21	0.025	0.013	0.101	0.08	0.37	0.10	0.78	5.47	5.8	1.01	1969.3	44.46
1989	890228	890530	0.27	0.038	0.015	0.195	0.15	0.68	0.15	0.88	5.85	6.8	1.04	1833.0	39.99
1990	900227	900529	0.25	0.033	0.017	0.144	0.22	0.88	0.21	0.57	5.86	6.3	1.10	1657.9	41.81
1991	910226	910604	0.22	0.025	0.017	0.091	0.12	0.72	0.09	0.61	5.37	6.7	1.07	9486.3	55.96
Summer															
1986	860603	860902	0.19	0.029	0.032	0.056	0.10	0.75	0.09	0.68	5.13	7.1	0.97	6396.3	15.93
1987	870602	870901	0.12	0.018	0.015	0.051	0.13	0.75	0.08	0.63	4.99	7.4	1.00	11485.4	21.31
1988	880531	880830	0.29	0.038	0.028	0.093	0.12	1.48	0.14	1.30	4.80	12.5	0.81	3988.6	6.32
1989	890530	890829	0.19	0.027	0.017	0.064	0.22	0.94	0.09	0.80	5.16	7.8	0.99	6824.5	13.35
1990	900529	900904	0.13	0.018	0.020	0.046	0.15	0.75	0.10	0.56	5.17	6.3	0.97	8087.5	22.06
1991	910604	910903	0.22	0.030	0.026	0.052	0.19	1.21	0.10	0.94	4.95	9.6	0.90	7841.9	12.86
Fall															
1986	860902	861202	0.07	0.010	0.012	0.131	0.04	0.40	0.06	0.40	5.31	4.4	1.05	4007.6	41.55
1987	870901	871201	0.06	0.014	0.010	0.114	0.06	0.39	0.08	0.51	5.17	6.1	1.04	3780.7	12.98
1988	880830	881129	0.18	0.027	0.015	0.126	0.01	0.68	0.10	0.69	4.99	8.0	1.01	1795.6	23.07
1989	890829	891129	0.22	0.029	0.015	0.168	0.12	0.84	0.17	0.65	5.70	6.5	0.92	3476.4	26.90
1990	900904	901204	0.10	0.016	0.006	0.040	0.06	0.65	0.09	0.38	5.30	5.0	0.79	4913.3	24.33
1991	910903	911203	0.04	0.007	0.010	0.106	0.06	0.60	0.15	0.34	5.21	5.1	0.80	3587.3	28.70

[1] *Cond. - Conductivity; µS/cm - microsiemens per centimeter; c/a Ratio - ratio of cations to anions; ml Svol - sample volume in milliliters; cm Ppt - centimeters of precipitation.*

Dry deposition is monitored at the Brooklyn Lake monitoring site with two samplers using filter pack technology, the Stacked Filter Unit (SFU) Network from University of California at Davis and the National Dry Deposition Network (NDDN) operated for the U.S. Environmental Protection Agency. The SFU filter pack is sent to the University of California at Davis for analysis. The analysis measures concentrations of elements from sodium to lead by particle-induced x-ray emission (PIXE), using the Crocker Nuclear Laboratory cyclotron. Also measured by the network are optical absorption (by laser integrating plate method, LIRM), fine mass and coarse mass particles (by gravimetric measurement), and hydrogen (by proton elastic scattering analysis, PESA). A sample of data output is listed in table 8.2.

The National Dry Deposition Network (NDDN) is a network of dry deposition monitoring sites in the United States operated for the U.S. EPA. An NDDN site located at GLEES is designated as the Centennial site, CNT169. The Centennial NDDN site is one of only 12 NDDN sites in the western United States. NDDN protocols collect dry deposition on a three-stage filter pack. Teflon, nylon, and paper filters each absorb different chemical species. All samples are analyzed in a central analytical lab located in Florida. NDDN filters are changed every Tuesday and sent to the lab for processing. NDDN sites also monitor meteorological conditions and ozone continuously. Data available from the NDDN site includes meteorological measurements of wind speed, wind direction, relative humidity, solar radiation, precipitation, and ambient temperature. Filter pack flow rate is also recorded at the site. Filter pack chemical analyses include sulfate, nitrate, ammonium, sodium, potassium, and nitric acid. Typical ozone data from the site for winter and summer is shown in figure 8.1.

A carbon dioxide monitor has been installed at the Brooklyn site for monitoring of ambient carbon dioxide. Measurements of carbon dioxide in the snowpack and soil at the Brooklyn site are also made at infrequent intervals.

Table 8.2.—Arithmetic mean values, December 1, 1990–February 28, 1991, Stacked Filter Unit (SFU) Particulate Network, Brooklyn Lakes SFU Site.

Particulate measurement	**24-hour concentration nanograms/cubic meter**
H	57.6
S	132.00
Al	15.30
Si	48.00
K	11.60
Ca	16.10
Ti	1.84
Mn	0.39
Fe	13.50
KNON	3.49
Na	6.47
Cl	3.07
V	0.84
Ni	0.44
Cu	0.79
Zn	0.87
As	0.13
Se	0.17
Br	0.62
Pb	0.68
Fine mass particles (<2.5 um)	1.95
Coarse mass particles (>2.5 and <15 um)	2.49
Reconstructed mass particles	1.21
SOIL (Sum of Al, Si, Ca, Ti, and Fe)	0.22
Ammonium sulfate (calculated)	0.54
Organic mass from hydrogen	0.34
Optical absorption	1.86

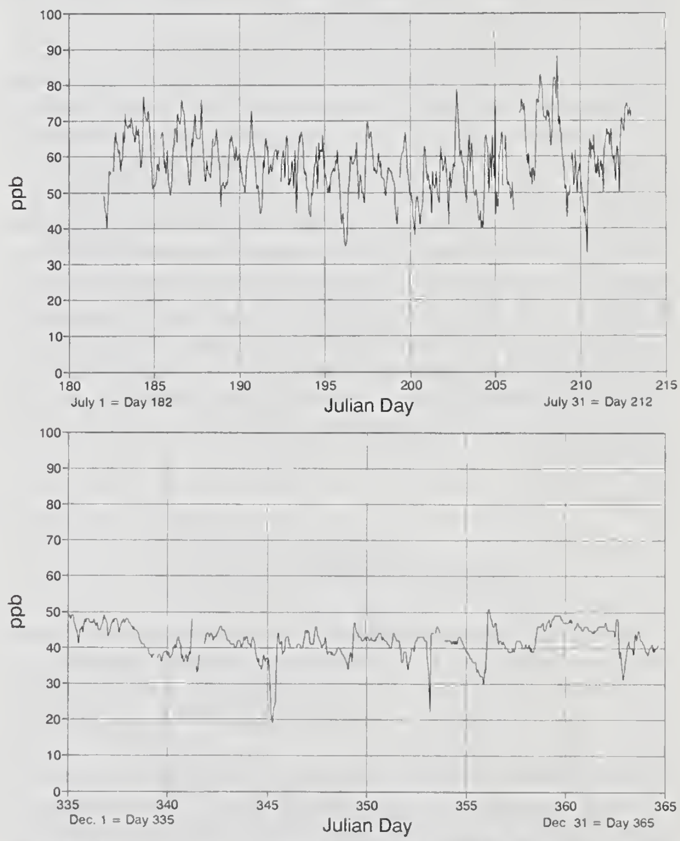


Figure 8.1.—Ozone concentrations in summer and winter from Centennial NDDN site, Brooklyn Lake, GLEES.

245

9. HYDROLOGY

V.C. Hasfurther, G.L. Kerr, G. Parks, and J. Wetstein
Wyoming Water Research Center
University of Wyoming
Laramie, Wyoming

Three Parshall flumes were installed within East and West Glacier Lakes watersheds during the summer of 1987. Each Parshall flume was prefabricated fiberglass construction fitted with a hypolon liner to bring as much groundwater flow as possible to the surface so that it could be measured by passing the water through the flume. The liner was buried as deep as was practical in front of the flume and to the sides of the flume for as reasonable a distance as was possible to intercept groundwater moving through the area. Some difficulty was encountered in burying the liner at all locations because of large boulders that could not be removed without substantial disturbance.

East Glacier Lake outlet was fitted with a 12-inch Parshall flume and associated stilling well, monitoring equipment, and shelter. Meadow Creek and Cascade Creek inlets to West Glacier Lake were both fitted with 9-inch Parshall flumes and associated stilling wells, recorders, and shelters. An 18-inch Parshall flume had been installed on the West Glacier Lake outlet in 1986. Plexiglass 90° V-notch weirs were fabricated to fit into the Parshall flumes for low flow measurements during the flow season. It was felt that the accuracy gained in measuring flow using the V-notches provided questionable additional accuracy because of substantial fluctuations in flow during the day and ice conditions occurring at night during the fall. V-notches were not used after 1988.

Preliminary Water Balance

Based on meteorological, precipitation, and flow measurement data collected on the GLEES site, an approximate water balance for East Glacier and West Glacier Lakes watersheds was developed. The water balance, and an estimation of the measurement errors associated with the development of the water balance for each watershed, is discussed here. This water balance is based upon limited data available in 1988. Additional data on inputs and flows will improve the calculations of water balance.

These two watersheds posed a unique problem in the development of a water balance because more water flows out of each watershed than is indicated as input from the precipitation gage measurements. For the West Glacier Lake watershed, this is believed to be a result of the large permanent (semi-glacial) snowfield that exists near the upper end (highest elevation areas near the watershed divide) of the watershed. These high-elevation and steep-relief areas collect blowing and drifting snow from adjacent watersheds because they are on the leeward side of the adjacent watersheds, in glacial cirques of the Medicine Bow ridge. Both lakes are close together, with East Glacier Lake at a higher elevation. The amount of water seepage from East to West Glacier Lake is unknown, but may also account for the lack of balance. In addition, the Wyoming-shielded precipitation gages are known to be inefficient collectors of snow in cold, windy areas.

Estimates of surface area hydrologic boundaries for East and West Glacier Lake watersheds used in the water balance studies were determined from a 1:12000 Snowy Range Observatory-Nash Fork Creek topographic map. The Nash Fork Creek map is a photo enlargement of the 1:24000 USGS map and was used because of the greater detail it offers. The East Glacier Lake watershed was selected to determine the extent of any enlargement distortion that may have occurred. Areas were determined with a K & E Vernier planimeter. Five measurements were taken from each map, and the high and low values were discarded. The mean of the remaining three values was calculated and compared. The results of this comparison indicate that the Nash Fork Creek map is suitable for use and that the enlargement process resulted in an overestimation of only approximately 1%. The measurements indicate an area of 24.7 ha (60.95 ac) for East Glacier Lake watershed and 59.3 ha (146.5 ac) for West Glacier Lake watershed. (Note: Actual watershed areas in Chapter 1 as determined from aerial photos are different from those calculated from maps and used for the analysis in this chapter.)

The isohyetal method was used to determine the average precipitation over the East and West Glacier Lake watersheds for the 1988 and 1989 water years. Four precipitation stations were used as control points. These four stations are Brooklyn Lake (0115A–35), Brooklyn Lake (0115–2), Lost Lake (0126), and Glacier Lake (0125). The monthly precipitation data for these stations were compiled from the WWRC Water Resources Data System database. This database extended through June of 1988, and supplemental data were compiled from the weekly strip charts of each station. Although lapses occur in the strip chart data, these omissions are unlikely to have a significant impact on the precipitation totals. The results of the isohyetal analysis indicate 84.10 cm (33.11 in) of precipitation (ppct) for West Glacier Lake watershed, and 95.35 cm (37.54 in) for East Glacier Lake watershed. The amount calculated for West Glacier Lake appears to be low, a result of an apparent under-collection for the Lost Lake precipitation gage and the lack of measurement of snow blown into the area of the permanent snowfield.

Three major streams exist in the Glacier Lakes area: Cascade, Meadow, and West Glacier Lake outlet. All three streams occur within the boundaries of the West Glacier Lake watershed area and all three are gaged with Parshall flumes. Cascade and Meadow Creeks discharge into West Glacier Lake and, as suggested by its name, West Glacier Lake outlet flows out of the lake. The East Glacier Lake watershed does not contain any perennial streams, but intermittent streams and overland flow drain into the lake until all snow cover is gone, and the outlet flows until late summer. Small ephemeral streams exist in the area within the watershed surrounding the lake.

The total annual flows for the Cascade, Meadow, and West Glacier Lake outlet were calculated for the 1988 water year. The record for this year extends from May 24 to September 30, with several daily records missing, as noted in WWRC Water Resources Data System database. It is assumed that although some flow may occur intermittently from October through April, these volumes are insignificant. Furthermore, records are not available for this time period.

A regression analysis was performed on Meadow and Cascade Creeks for the 1988 water year to derive missing streamflow data for Cascade Creek during that year. The Minitab statistical software package was used to perform the analysis. A review of the database and regression analysis found a water yield of 138.84 ac ft annual flow from Cascade Creek, 110.10 ac ft annual flow from Meadow Creek, for a total of 248.94 surface flow into West Glacier Lake from Cascade and Meadow Creeks. West Glacier outlet flow was 623.72 ac ft for May 24 through Sept 30, 1988. Monthly flow data is presented in table 9.1. The data suggest that the high flows in Cascade Creek, as reflected by the mean monthly flows, are lagged relative to the high flows in Meadow Creek. The direct correlation between the two streams for the period of record available is generally poor, with the exception of the month of July. The flow lag and correlation differences are difficult to explain.

Lag of High Flows

Although both Cascade and Meadow Creeks are in steep, rugged terrain with similar geological features, differences exist between the two watersheds. Cascade Creek is fed primarily by the permanent snowfield and is strictly channelized flow. Meadow Creek is also fed by the permanent snowfield, but is less steep terrain, has large areas of the catchment that melt out, and runs through a large meadow area uphill from the outlet. Although the 1988 isohyetal map suggests that precipitation over the two catchments is essentially the same, more snow is likely deposited in the area of the permanent snowfield, affecting Cascade Creek more than the Meadow Creek catchment. These differences may influence the lag of high flows in the two catchments.

Table 9.1.—Monthly flows for Cascade Creek, Meadow Creek, and West Glacier Lake outlet, 1988.

	May	June	July	Aug	Sep	Total
Meadow Creek						
Total (cfs)	3.79	22.50	16.61	8.96	3.67	
Mean (cfs)	.47	.75	.54	.29	.12	
Ac ft	7.46	44.63	32.95	17.77	7.28	110.09
Cascade Creek						
Total (cfs)	2.72	24.40	21.96	14.50	6.36	
Mean (cfs)	.34	.81	.71	.47	.21	
Ac ft	5.40	48.38	43.66	28.90	12.50	138.84
West Glacier Lake outlet						
Ac ft	46.73	262.81	199.54	81.12	33.52	623.72

Variations in net solar radiation input between the two areas may be partially responsible for the lag. The topographic map indicates that this area scribes a 1/4 circle from north to NW, with Meadow Creek flowing generally north to south, and Cascade Creek flowing NW to SE. The differences in slope aspect may be sufficient to cause the observed lag in flows because the Meadow Creek watershed would receive more direct solar radiation input for a longer duration of time during the late spring and summer months. The result would be that the snowpack in the Meadow Creek watershed would begin to melt earlier and at a faster rate than the snowpack in the Cascade Creek watershed and would be expressed as larger early season flow, as observed.

The above hypothesis is based on limited information. To determine the validity of this hypothesis, the necessary equipment to determine the solar radiation influx has been installed. The data provided by the instrumentation will allow for the calculation of potential rates of melting. In addition, the potentially significant effects of a large permanent snowfield in this area can not be ignored. It has been assumed, for purposes of the above argument, that this snowfield covers both watersheds uniformly and can therefore be considered a constant (i.e., affecting the watersheds in a manner similar to uniform precipitation). In reality, most of the Meadow Creek watershed melts out, with only a small portion of this watershed fed by the snowfield after July. Much of the upper portion of the Cascade Creek watershed is snow-covered year round. Cascade Creek also has much steeper relief than Meadow Creek, which may be related to the differences.

Correlation of Streamflows

As indicated, the data show poor correlation, with the exception of the month of July. Although this poor correlation may be due to random events, it is proposed that what may actually be occurring is a transition between two states of equilibrium. These two states of equilibrium are categorized, for purposes here, as "winter equilibrium" and "summer equilibrium" with the transition between the two states occurring at different rates in the two catchments. The winter equilibrium state for both catchments would be characterized by the following conditions:

1) Soil and zone of interflow are frozen to the frost line.

2) Deactivation of the groundwater system directly results from this interflow.
3) Losses in the catchment are only a result of surface flow, evaporation (sublimation), and transpiration (affecting only waters directly adjacent to roots of coniferous vegetation).

The period of equilibrium under these conditions would exist from late October or early November to late April or early May.

The summer equilibrium state would be characterized by different conditions. These would include:

1) An entirely thawed zone of interflow.
2) An entirely reactivated groundwater system as a direct result of this interflow.
3) Losses in the catchment resulting from surface flow, evaporation and/or sublimation, and transpiration at maximum rates; and groundwater flow.

The period of equilibrium under these conditions would exist in mid-summer (July and August).

Between these two equilibrium extremes the following conditions would exist:

1) A gradually thawing or freezing zone of interflow.
2) A gradual reactivation or deactivation of groundwater systems in response to this interflow.
3) A gradual increase or decrease in evaporation and/or sublimation, and transpiration at gradually increasing or decreasing rates.

These intermediate conditions would occur from late April or early May to September and October, with one of the two proposed equilibrium conditions occurring before or after this transitory state.

Evaporation

The mass transfer method was used to calculate the reservoir evaporation for East and West Glacier Lakes. This method was selected over other methods because the more extensive data required by these other methods were not available. The mass transfer method uses the formula:

$$E = c(e_o - e_a)(1 + [w/10])$$

where
E = inches/month
c = 14
e_a = saturation vapor pressure at mean monthly temperature in inches Hg
e_o = vapor pressure at mean monthly temperature in inches Hg
w = mean monthly windspeed at 25 ft (mi/hr).

The data used here were obtained from a totalizing anemometer and hygrothermograph located at the Telephone Lakes station and better reflect conditions at Glacier Lakes when compared to other Snowy Range Observatory stations in the area. Factors considered when selecting this station included topography, elevation, and exposure. More recent wind speed data is now available from the GLEES meteorological tower but was not available for this analysis.

It was assumed that a free surface exists from June 1 to September 30 and that evaporation occurs only during this time interval. It is further assumed that the surface area of the lakes remained constant. The computed total annual loss by evaporation is 9.9 ac ft from West Glacier Lake. Assuming the same surface area for East and West Glacier Lakes, the total evaporation loss from East Glacier Lake is also 9.9 ac ft.

The Blaney-Criddle method was used to determine the evapotranspiration losses for both catchments. As with the mass transfer method, this method was selected because the more extensive data required by other methods were not available. It was assumed that the total evapotranspiration for the season could be reasonably approximated by considering only the losses occurring between June 1 and September 30, which is the period of maximum plant growth. A significant fraction of the watershed areas consists of bare rock with negligible moisture-holding capacity. Evaporation from such a surface would be limited to the drying of a wet surface immediately after a precipitation event. Therefore, the majority of moisture returned to the atmosphere occurs over areas where soil development is sufficient to retain water and support plant life. The evapotranspiration estimate must therefore be adjusted to reflect the percentage of groundcover in the catchment. For computational purposes it has been assumed that 35% groundcover exists in both catchments and that a linear relationship exists between percent groundcover and total evapotranspiration losses. The results of the computations indicate that 288.1 ac ft of moisture is lost via evapotranspiration over the West Glacier Lake watershed and 119.9 ac ft is lost over the East Glacier Lake watershed during the indicated time period.

Water Budget

Using the values computed for surface discharge, evapotranspiration, and precipitation input, a water budget was calculated for East and West Glacier Lakes. Total change in storage is calculated as:

$$S = P - (E + E.T. + Q + G)$$

where
S = change in storage
P = precipitation over watershed
E.T. = evapotranspiration
Q = surface flow
G = groundwater
E = lake evaporation.

The water budget computations for West Glacier Lake indicate that 517.5 ac ft more of water was discharged from the catchment than was being supplied by precipitation input. By these estimates, the snowfield is contributing about 128% more water than is contributed by precipitation over the watershed. It is proposed that this excess moisture is being supplied by the large permanent snowfield at the top of the watershed. This

snowfield straddles the northwestern portions of the East and West Glacier Lakes watersheds and was formed and is maintained by blowing snow deposited on the leeward side of the mountain peaks. This snowfield represents a net moisture input to the catchments that is not recorded by precipitation gages located lower in the catchment.

An estimate of the size of the snowfield needed to produce the required volume of water can be made by selecting a density value for the snow and calculating the equivalent water content on a volume basis. Then, by selecting various values for the depth of snow, the areal size can be computed. Such computations indicate that for a density of 2.8 pounds/cu foot and a 10-ft uniform depth, the snowfield would have to cover 119 acres. For a 20-ft depth, 59.5 acres would be required. Direct observations of the size of the snowfield indicates that these values are not completely unreasonable as upper and lower size limits and that the largest amount of unaccounted outflow comes from this snowfield. It is observed during the summer season that a large amount of flow into West Glacier Lake and to the outlet of the lake results from melting of the permanent snowfield. Water can be heard running through Long Creek to the west of Cascade Creek, and also in the large boulders in Boulder Creek, a small drainage to the east of Meadow Creek. The boulders in these two drainages preclude flow measurement by flume, thus flow data are not available from Boulder and Long Creeks.

Water not moving through stream channels will flow by subconcentrated surface flow, surface flow, interflow, or groundwater flow. Because there is only one unconfined alluvial aquifer in the area, near surface interflow should not occur until the entire depth of the aquifer is saturated. Assuming that the groundwater and interflow systems can be considered as one system, calculations can be made to determine the volumetric flow rates of groundwater and subconcentrated surface water. These calculations estimate 9.394×10^5 gal/day flows as subconcentrated surface flow, interflow, and groundwater flow in the West Glacier Lake watershed from May 24 to September 30. However, several other quantities can contribute to the outflow in West Glacier Lake, including subsurface flow from East Glacier Lake into West Glacier Lake. The 26.1 ac ft of unaccounted water from the East Glacier Lake water balance could be seeping into West Glacier Lake. The largest problem in this whole water balance effort is the unknown of groundwater movement in the area.

Errors Associated With Water Balance

An excellent summary of the problems associated with water balance studies on lakes is given in a paper by Winter (1981) entitled "Uncertainties in Estimating the Water Balance of Lakes." These same problems exist with trying to do water balance studies on East and West Glacier Lakes and their watershed areas. Winter (1981) estimates errors for the following components of hydrologic measurement:

measuring precipitation in individual storms — 75%
short-term averages — 15–30%
evaporation estimates — 10–15%
stream discharge — 5% +
overland flow — unknown, but can be over 100%.

Accumulation of these errors gives an idea of the difficulty of obtaining precise estimates of watershed water balances. The additional difficulty of obtaining accurate data from remote watersheds in complex terrain such as the Glacier Lakes makes water balance estimates even more uncertain. Nevertheless, we have made preliminary estimates of water balance for the Glacier Lakes that will be further refined as additional measurements of the components of water balance provide more accurate data.

It is difficult to estimate evaporation and evapotranspiration accurately by the methods used. The values obtained could represent 75–100% error. A pan evaporimeter has been installed at the site to obtain more accurate estimates of evaporation.

Streamflow measurements of surface water discharge should generally be within 5% of actual because of the Parshall flumes being used, except during fall freeze periods. On a yearly basis, however, the values obtained should definitely be within 5%, except perhaps for West Glacier Lake outlet. During most of the year, a small amount of seepage occurred at the outlet of West Glacier Lake under the hypalon cutoff liner that could amount to as much as 0.5 cfs during larger flows and approximately 0.25 cfs during the fall period. This leak was repaired in 1989, but some leakage was noted again in 1991.

Groundwater flow was considered to be in balance over a yearly period. This assumption should be approximately true with errors in the range of 5–10%. However, it is believed that seepage does occur from East Glacier into West Glacier, which could account for some of the difference. Any water balance studies done on less than a yearly period would have to account for groundwater movement into and out of the area. The amount of groundwater movement out of the two watershed areas could be sizeable during certain months such as June, July, and August.

It is believed that the largest source of error in the West Glacier Lake watershed is the permanent snowfield that exists along the north and west ends of the watershed divide. It is believed that the accumulation of blowing snow from adjacent watersheds, along with the difference between yearly hold-over storage of the snowfield, can result in over 100% error in estimation of the water balance of West Glacier Lake. It is indicated from the water balance study done that this phenomena is not as pronounced for East Glacier Lake.

Suggestions for Error Minimization

The following ideas and/or suggestions are made to reduce the errors associated with a water balance study on either East or West Glacier Lake watersheds.

Precipitation gages should be checked to make sure that they are operating correctly and the weighing mechanisms are accurate to within the limits of the instrumentation as indicated by the manufacturer. All precipitation gages should be shielded from the wind since much of the area is subject to high winds during the winter period. Additional precipitation and snow survey data have been collected (in 1989 and 1990) since this analysis was made (for 1988), which indicate that the precipitation collectors are inefficient collectors of snow. In addition, the location of the SRO precipitation collector at Glacier Lakes is on a ridgetop where deposition is considerably lower than that in other portions of the East and West Glacier Lakes watersheds.

A land evaporation pan has been installed within the entire watershed area so that the estimates of evaporation and evapotranspiration can be made more accurately than was done under this study of water balance. This data was collected beginning in 1991.

A detailed snow survey of the two watershed areas is necessary in late April or when the snowpack is close to being ripe to determine the actual amount of water stored during the winter period as a result of precipitation and blowing snow accumulation from adjacent watersheds. This task could be very difficult on the West Glacier Lake watershed because of the cornices that are formed as a result of the blowing snow.

The permanent snowfield needs to be measured in the fall of each year near the end of the melt period for the snowfield. The change in volume each year can then be determined. It will be necessary to get a reasonably accurate estimate of the density of the snowfield at this time also.

Any water balance studies made over a shorter period than one year will need to include runoff occurring either as overland flow directly into the lake or unmeasured surface inflow that cannot be obtained due to boulder fields. Both of these estimations (groundwater movement and unmeasured surface flows) on these two watershed areas can reflect as much as 100% or greater errors in the water balance. No easy solution to these problems exist. Physical measurement techniques to quantify the amount of water input to or output from the given lake water balance in these two watersheds is almost impossible without an undue amount of land disturbance.

Groundwater movement can be estimated by placing piezometers at selected locations throughout the watershed area to determine groundwater gradients. Using an estimate for hydraulic conductivity that can be done either by estimation from soil type and structure or infield tests (several available including pumping), Darcy's Law can be applied to a cross section of the area to determine flow. Cross sections can be obtained in these areas using surface geophysical techniques.

Finally, the hypalon liners of the flumes should be periodically checked to prevent as much seepage as possible from under the liner.

Depth Measurement of Unconsolidated Material

In order to get a better feel for possible groundwater movement in the East and West Glacier Lake watersheds, a number of cross sections were selected to obtain the depth of unconsolidated material available for groundwater flow throughout the watersheds. A surface geophysical technique known as seismic refraction was performed using a hammer to create the sound wave and several geophones to detect the sound wave movement to determine the depth to bedrock material.

Eight different cross sections were obtained using the seismic refraction technique. Figure 9.1 has a map that indicates the location of the eight cross sections. Each of the eight cross sections is schematically shown (figs. 9.2–9.8) as determined from the seismic refraction data.

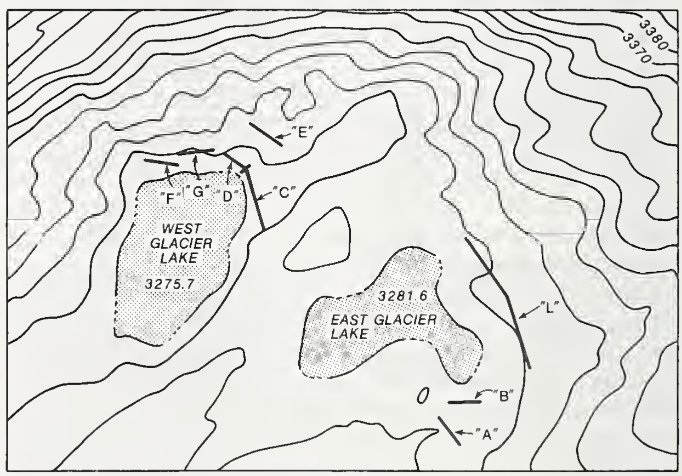


Figure 9.1.—Map showing locations of cross sections used to determine depth of unconsolidated material.

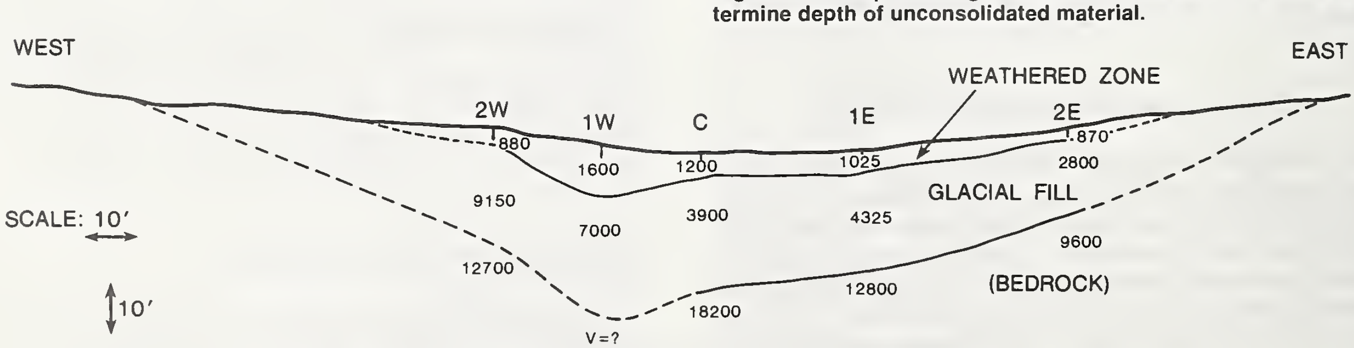


Figure 9.2.—Cross section A. Depth of unconsolidated material.

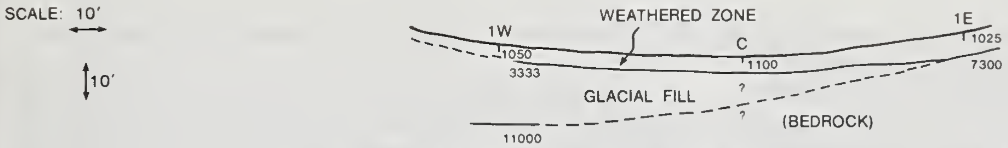


Figure 9.3.—Cross section B. Depth of unconsolidated material.

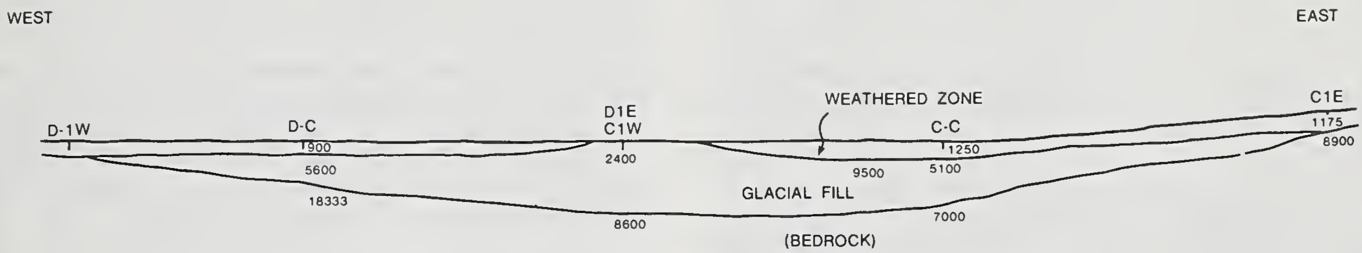


Figure 9.4.—Cross sections C and D. Depth of unconsolidated material.

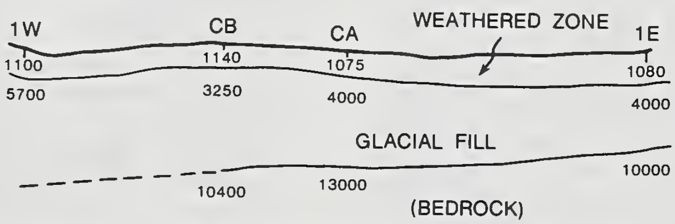


Figure 9.5.—Cross section E. Depth of unconsolidated material.

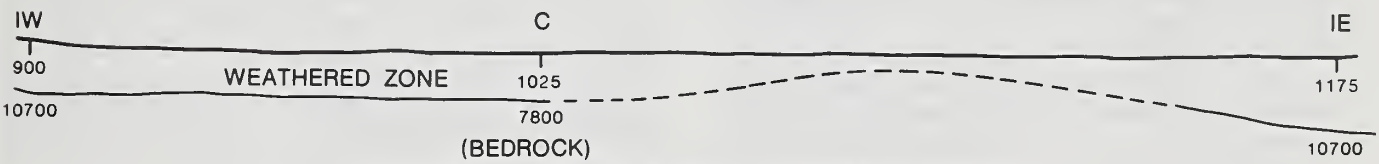


Figure 9.6.—Cross section F. Depth of unconsolidated material.

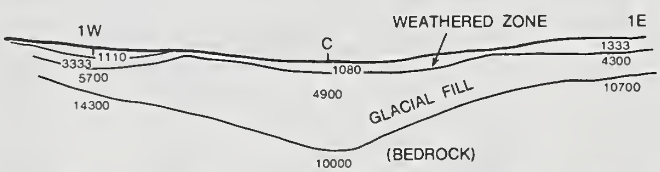


Figure 9.7.—Cross section G. Depth of unconsolidated material.

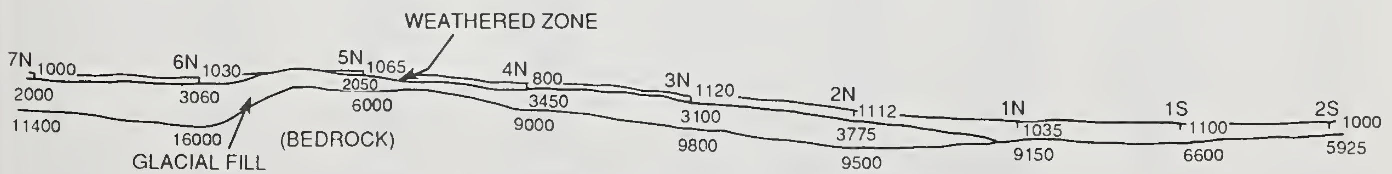
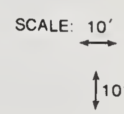


Figure 9.8.—Cross section L. Depth of unconsolidated material.



Most of the depths to the base of the weathering layer (velocity 200–500 fps) are quite reliable. The layer with velocities in the range from 200–4,000 fps is probably glacial material. Velocities above 4,000 fps and up to 7,000 fps are at a higher velocity than would be expected for glacial debris, but it is possible. The cross sections drawn are, therefore, the author's interpretations. The granite bedrock material was expected to have a velocity around 16,000–18,000 fps. Since these velocities were not measured that often, it could be possible for the glacial material to be as much as 20 feet thick (as is shown on most of the cross sections) on a highly disturbed bedrock surface, which would account for the slower velocities measured in several instances.

A crude estimate of hydraulic conductivity was determined using information from the water balance study and the seismic refraction cross-sections. Values for the hydraulic conductivity were found to be between 25 and 146 gpd/ft². Conductivity (K) can be calculated from the formula:

$$Q - KIA = > K = Q/IA$$

where

Q = Volumetric flowrate gal/day
I = Hydraulic gradient
A = Area perpendicular to flow
K = Hydraulic conductivity.

For West Glacier Lake watershed assume:

1) All nonchanneled flow moves in the groundwater aquifer, i.e., no subconcentrated surface flow.
2) Q = 939,400 gal/day.
3) The hydraulic gradient is unity, i.e., 1ft/ft.
4) The area perpendicular to flow can be completely accounted for from the seismic profiles. For WGL shot lines "C-D," "F," and "G" the entire thickness is saturated.

5) $K = \dfrac{939{,}400 \text{ gal/day}}{(1\text{ft/ft})\ (6{,}425\text{ft}^2)}$

6) $K = \dfrac{146.2\ GPD}{\text{ft}^2}$

Evaluation of Hydraulic Conductivity Analysis

The hydraulic conductivity calculated falls at the upper limit of conductivities for glacial tills (10^{-6} to 10^{2}). The problem with the analysis is that none of the assumptions used in performing the calculation can truly be justified. There is no reason to believe, for example, that all of the nonchannelized flow moves in the groundwater system or that the hydraulic gradient is unity. The area perpendicular to flow is certainly much greater than that calculated from the refraction survey as the shot lines cover only a fraction of the potential contributing area.

However, in spite of these shortcomings, the K value calculated may not be totally erroneous when the following observations are taken into account:

1) If the fraction of nonchannelized flow entering the groundwater system is only 10% of the total nonchannelized flow (93,940 gal/day) the resulting conductivity is only decreased by one order of magnitude.
2) Although the hydraulic gradient is most likely some fraction of unity, it is definitely known that the aquifer area perpendicular to flow is much greater than the 6,425 ft² value used. Therefore, the effects of decreased gradient and increased area will tend to offset each other resulting in minimal changes in the conductivity. For example, if I = .5 ft/ft and 2A = 12,850 ft², there will be no change at all in the conductivity.

In conclusion, although the individual assumptions may not be justifiable, the overall affect may be negligible. Therefore, the hydraulic conductivity value of K = 146.2 GPD/ft² for this aquifer may be very close to the true value, which can only be determined with further and more extensive study.

Reference

Winter, T.C. 1981. Uncertainties in estimating the water balance of lakes. Water Resources Bulletin. 17(1): 82–115.

10. SNOW

R.A. Sommerfeld
Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado

Generally, the annual snowpack at GLEES is established in November and lasts into July. Figure 10.1 is the 1987–91 recession curve of the snow- covered area fraction versus degree days. About 20% of the area consists of rocks, which are usually blown clear of snow, and trees. The trees may hide some of the snow in the aerial photographs that were used to develop the curve. The remnant area fraction of snow cover represents the permanent snowfield on the cliff face overlooking the lakes.

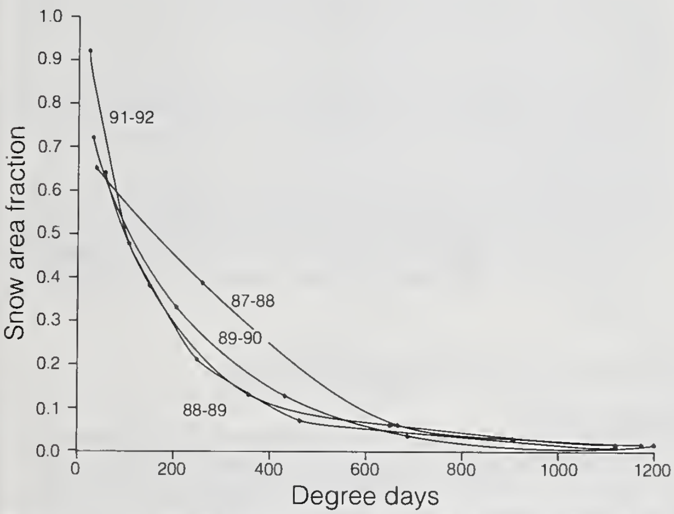


Figure 10.1.—1987–88 snow recession curve of snow-covered area of GLEES versus degree days beginning at first melt. Snow area was measured from aerial photos.

The permanent snowfield is the result of wind transport of snow from the plateau to the north into the catchment area formed by the cliff face. In general, wind transport of snow is very important in GLEES. This is reflected in the snow's uneven distribution, its obvious drifting, and its density, which is usually above 300 kg m^{-3} throughout the winter.

Table 10.1 gives the precipitation from snowfall collected at the Wyoming Water Research Center Snowy Range Observatory precipitation gage between East and West Glacier Lakes for the 13 winters from 1976–77 through 1988–89. According to this gage, the average precipitation is 68 cm of water during the winter period. This gage likely under-collects because of its location on a snow-free, wind-swept ridge and because of the design of the wind shield.

A study to determine the long-term snow depth from the deformation of the trees on the watershed was conducted (Wooldridge et al. 1993). The average snow depth over the watershed determined by this study is 200 cm. The average snow density found in snow pits dug at maximum accumulation (Bales et al. 1990) was 401 kg m^{-3}. If this average is representative of the watershed,

Table 10.1.—Winter precipitation at GLEES, Snowy Range Observatory Glacier Lakes precipitation collector (data provided courtesy of Wyoming Water Research Center). Monthly averages exclude months with missing data. Seasonal totals used monthly averages for months with missing data, unless monthly accumulation was already greater than average.

	inches of precipitation collected							
Year	Nov	Dec	Jan	Feb	Mar	Apr	Total	Total cm
76–77	0.74*	1.89*	1.60*	1.18*	0.77*	2.66*	ins	
77–78	1.84*	4.22*	1.29	0.78	2.30	na	ins	
78–79	0.92*	na	0.34*	2.74*	1.79*	2.15*	ins	
79–80	5.47	3.41	8.11*	5.77*	7.38	5.48	35.62	90.47
80–81	1.72	2.26	2.33	4.88	4.01	3.02	18.22	46.29
81–82	3.03	7.40	2.95+	2.81	8.80	3.80*	28.79	73.13
82–83	4.57	5.68	6.38	5.19	9.60	4.70	36.12	91.74
83–84	7.00	7.01	1.87	1.76	3.64	3.34	24.62	62.53
84–85	4.96	6.30	3.85	2.51	5.69	5.51	28.82	73.20
85–86	9.16	6.24	4.25	7.88	3.35	5.10	35.98	91.39
86–87	3.53	0.36	2.34	1.46	2.24	1.16	11.09	28.17
87–88	2.12*	3.88	6.23	3.58	6.26	1.91	26.81	68.10
88–89	5.15	3.00	2.84	3.99	3.84	2.74	21.56	54.76
Average:	4.95	4.55	3.43	3.66	5.19	3.66		67.98

** – record with missing data.*
na – no data available.
ins – insufficient data available to calculate seasonal total.
+ – total for January 1982 differs from Wyoming Water Research Center data. Average for this month was corrected upon examination of database. Subsequent corrections by Wyoming Water Center are slightly different (table 7.1).

the average winter accumulation using these data is 80 cm H_2O. A map of distribution of snow depths at GLEES is available (Wooldridge et al. 1993). It was based on the tree study, and the contours were adjusted to conform to aerial photography of the snow distribution on June 22, 1988. It was possible to make these adjustments without violating the point depths determined from the tree forms.

An estimate of the snow accumulation was made for winter 1987–88 using the technique of Martinec and Rango (1986). The estimated accumulation was 85 cm H_2O, about 106% of the long-term average estimated above. The Wyoming Water Research Center Snowy Range Observatory precipitation gage measured about 68 cm H_2O, about 89% of average. Taking into account the various errors in the estimates, we have concluded that the Martinec Rango estimate of 85 cm of H_2O is likely within + 10% for the snow accumulation in the winter 1987–88 (Sommerfeld et al. 1990). The disagreements among the estimates cannot be resolved with present data. In fact, the accurate measurement of winter precipitation into alpine watersheds is a very difficult problem and the disagreements probably cannot be resolved without the application of novel methods.

Table 10.2 shows the average concentrations of several ionic impurities for snowpits dug during 1987–88. Samples from lysimeters under the snow showed ionic pulses that concentrated these ions from 4–10 times above their average concentrations. Typical of snowpacks in this climate, the water flow from the base does not begin until mid-May and continues until the seasonal snow is completely melted. This contrasts with climates in warmer areas that may have melt episodes at any time during the winter. For this reason, GLEES is ideal for studying the episodic effects from snowmelt.

References

Bales, R.; Sommerfeld, R.A.; Kebler, D.G. 1990. Ionic tracer movement through a Wyoming snowpack. Atmospheric Environment. 24A(11): 2749–2758.

Martinec, J.; Rango, A. 1986. Parameter values for snowmelt runoff modelling. Journal of Hydrology. 84: 197–219.

Sommerfeld, R.A.; Musselman, R.C.; Wooldridge, G.L. 1990. Comparison of estimates of snow input to a small alpine watershed. Journal of Hydrology. 120: 295–307.

Wooldridge, G.I.; Musselman, R.C.; Sommerfeld, R.A.; Fox, D.G.; Connell, B.H. Mean wind patterns and snow depths in an alpine-subalpine ecosystem as measured by damage to coniferous trees. [Manuscript in preparation].

Table 10.2.—Average snow pit concentrations at snow lysimeter site, east of East Glacier Lake, 1988.

			Concentration, µeq L^{-1}								µM		
Pit	Snow water equivalent m	Conductivity µS	SO_4^{2-}	NO_3^-	Cl^-	Br^-	Ca^{2+}	Na^+	Mg^{2+}	K^+	A1(III)	Silica	H^+
2	0.58	—	11.7	6.9	1.7	0.0	—	—	—	—	—	—	—
3	0.63	—	9.7	9.7	5.4	0.0	—	—	—	—	—	—	—
4L	0.85	—	12.9	9.8	1.7	0.1	8.6	5.8	2.5	0.9	1.4	1.5	—
4R	0.77	—	14.4	9.4	2.0	0.8	16.3	14.7	15.9	12.2	1.8	1.8	—
5L	0.94	5.0	8.2	7.8	2.1	0.0	6.9	1.2	1.8	2.0	0.4	0.8	4.39
5R	0.94	5.2	8.7	8.6	2.2	0.0	7.9	2.7	1.8	1.1	0.6	1.4	4.30
6L	0.85	4.7	6.0	7.8	1.4	0.0	—	—	—	—	—	—	6.47
6R	0.88	4.7	7.1	7.8	2.1	0.0	—	—	—	—	—	—	5.98

Appendix A
Vascular Plants of GLEES

J.D. Haines and C.M. Regan
Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado

This appendix provides a list of 230 vascular plant taxa that were field identified and/or collected over the period 1986–1990. Field identification was done by C.L. Simmons in 1986–87 (see Chapter 2). Subsequent taxa were field identified, collected, and verified by J.D. Haines and C.M. Regan in 1988–90. Voucher specimens were verified by taxonomists at the Rocky Mountain Herbarium. All taxa were collected in the upper GLEES area encompassing the watersheds of East and West Glacier Lakes and Lost Lake. A herbarium voucher collection of plant species found at GLEES is maintained at the Rocky Mountain Herbarium in Laramie, in cooperation with the University of Wyoming. A duplicate collection is housed at the Centennial, Wyoming, field laboratory.

References

Cronquist, A.; Holmgren, A.H.; Holmgren, N.H.; Reveal, J.L. 1972. Intermountain flora, volume 1. New York: Hafner Publishing. 270 p.

Cronquist, A.; Holmgren, A.H.; Holmgren, N.H.; Reveal, J.L.; Holmgren, P.K. 1977. Intermountain flora, volume 6. New York: Columbia University Press. 584 p.

Cronquist, A., Holmgren, A.H.; Holmgren, N.H.; Reveal, J.L.; Holmgren, P.K. 1984. Intermountain flora, volume 4. Bronx, NY: The New York Botanical Garden. 573 p.

Cronquist, A.; Holmgren, A.H.; Holmgren, N.H.; Reveal, J.L.; Holmgren, P.K. 1989. Intermountain flora, volume 3. Bronx, NY: The New York Botanical Garden, Bronx, New York. 279 p.

Gray, A.; Hooker, J.D. 1880. The vegetation of the Rocky Mountain region and a comparison with that of other parts of the world. Bulletin of the United States Geological and Geographical Survey of the Territories. 6(1): 1–62.

Harrington, H.D. 1964. Manual of the plants of Colorado. Chicago: The Swallow Press. 666 p.

Harshburger, J.W. 1911. Phytogeographic survey of North America. Vegetation d. Erde 13 63. Engelmann, Weinheim. 790 p.

Hitchcock, C.L.; Cronquist, A. 1973. Flora of the Pacific Northwest. Seattle: University of Washington Press. 730 p.

Hitchcock, C.L.; Cronquist, A.; Ownbey, M.; Thompson, J.W. 1955. Vascular plants of the Pacific Northwest, part 5. Seattle: University of Washington Press. 343 p.

Hitchcock, C.L.; Cronquist, A.; Ownbey, M.; Thompson, J.W. 1959. Vascular plants of the Pacific Northwest, part 4. Seattle: University of Washington Press. 510 p.

Hitchcock, C.L.; Cronquist, A.; Ownbey, M.; Thompson, J.W. 1961. Vascular plants of the Pacific Northwest, part 3. Seattle: University of Washington Press. 614 p.

Hitchcock, C.L.; Cronquist, A.; Ownbey, M.; Thompson, J.W. 1964. Vascular plants of the Pacific Northwest, part 2. Seattle: University of Washington Press. 597 p.

Hitchcock, C.L.; Cronquist, A.; Ownbey, M.; Thompson, J.W. 1969. Vascular plants of the Pacific Northwest, part 1. Seattle: University of Washington Press. 914 p.

Holm, T. 1923. The vegetation of the alpine region of the Rocky Mountains in Colorado. Memoirs of the National Academy of Sciences. 19(3): 1–45.

Hulten, E. 1968. Flora of Alaska and neighboring territories. Stanford, CA: Stanford University Press. 1008 p.

Hulten, E.; Fries, M. 1986a. Atlas of north European vascular plants north of the Tropic of Cancer, volume 1. Germany: Koeltz Scientific Books. 498 p.

Hulten, E.; Fries, M. 1986b. Atlas of north European vascular plants north of the Tropic of Cancer, volume 2. Germany: Koeltz Scientific Books. 968 p.

Hulten, E.; Fries, M. 1986c. Atlas of north European vascular plants north of the Tropic of Cancer, volume 3. Germany: Koeltz Scientific Books. 1172 p.

Kearney, T.H.; Peebles, R.H. 1964. Arizona flora. Berkeley: University of California Press. 1085 p.

Komarkova, V. 1979. Alpine vegetation of the Indian Peaks area. Germany: J. Cramer. 591 p.

Martin, W.C.; Hutchins, C.R. 1980. A flora of New Mexico, volume 1. Germany: J. Cramer. 1276 p.

Martin, W.C.; Hutchins, C.R. 1981. A flora of New Mexico, volume 2. Germany: J. Cramer. 2591 p.

McGregor, R.L. 1986. Flora of the Great Plains. Lawrence, KS: University Press of Kansas, Lawrence, Kansas. 1392 pp.

Moss, E.H. 1983. Flora of Alberta, second edition (revised by John G. Packer). Toronto, Canada: University of Toronto Press. 687 p.

Rydberg, P.A. 1913. Phytogeographical notes on the Rocky Mountain region. I. Alpine region. Bulletin of the Torrey Botanical Club. 40: 677–686.

Rydberg, P.A. 1914a. Phytogeographical notes on the Rocky Mountain region. II. Origin of the alpine flora. Bulletin of the Torrey Botanical Club. 41: 89–103.

Rydberg, P.A. 1914b. Phytogeographical notes on the Rocky Mountain region. III. Formations in the alpine zone. Bulletin of the Torrey Botanical Club. 41: 459–474.

Rydberg, P.A. 1915a. Phytogeographical notes on the Rocky Mountain region. IV. Forests of the subalpine and montane zones. Bulletin of the Torrey Botanical Club. 42: 11–25.

Rydberg, P.A. 1915b. Phytogeographical notes on the Rocky Mountain region. V. Grasslands of the subalpine and montane zones. Bulletin of the Torrey Botanical Club. 42: 629–642.

Rydberg, P.A. 1916. Phytogeographical notes on the Rocky Mountain region. VI. Distribution of the subalpine plants. Bulletin of the Torrey Botanical Club. 43: 343–364.

Rydberg, P.A. 1917. Phytogeographical notes on the Rocky Mountain region. VII. Formations in the subalpine zone. Bulletin of the Torrey Botanical Club. 44: 431–454.

Rydberg, P.A. 1919. Phytogeographical notes on the Rocky Mountain region. VIII. Distribution of the montane plants. Bulletin of the Torrey Botanical Club. 46: 295–327.

Rydberg, P.A. 1920. Phytogeographical notes on the Rocky Mountain region. IX. Wooded formations of the montane zone of the southern Rockies. Bulletin of the Torrey Botanical Club. 47: 441–454.

Rydberg, P.A. 1921. Phytogeographical notes on the Rocky Mountain region. X. Grasslands and other open formations of the montane zone of the southern Rockies. Bulletin of the Torrey Botanical Club. 48: 315–326.

Weber, W.A. 1965. Plant geography in the Southern Rocky Mountains. In: Wright, H. E., Jr.; Frey, D. G., eds. The quaternary of the United States. Princeton, NJ: Princeton University Press: 453–468.

Weber, W.A. 1967. Rocky Mountain flora. Boulder: University of Colorado Press. 437 p.

Weber, W.A. 1987. Colorado flora: Western Slope. Boulder: Colorado Associated University Press. 530 p.

Weber, W.A. 1990. Colorado flora: Eastern Slope. Boulder: University of Colorado Press. 396 p.

Welsh, S.L. 1974. Anderson's flora of Alaska and adjacent parts of Alaska. Provo, UT: Brigham Young University Press. 724 p.

Welsh, Stanley L.; Atwood, N. Duane; Goodrich, Sherel; Higgins, Larry C. eds. 1987. A Utah flora. Great Basin Naturalist Memoirs 9. Provo, UT: Brigham Young University Press. 894 p.

Family	Botanical name [1]	Distribution [2]	Common name
Isoetaceae	*Isoetes bolanderi* Engelm. var. *bolanderi*	BM, WNAm	Bolander quillwort
Ophioglossaceae	*Botrychium lunaria* (L.) Sw. var. *lunaria*	BM, C-SAm-Aus-NZ	Moonwort, Moonwort grapefern
Polypodiaceae	*Cryptogramma acrostichoides* R. Br.	BM, C	Parsley-fern, Mountain-parsley, American rockbrake, Rock-brake
	Cystopteris fragilis (L.) Bernh. var. *fragilis*	M, C-SAm-Afr-Ant	Brittle-fern, Brittle bladderfern
	Woodsia scopulina D. C. Eat.	M, NAm	Rocky Mountain Woodsia
Selaginellaceae	*Selaginella densa* Rydb.	M, WNAm	Spikemoss Selaginella, Little club-moss, Rock spikemoss, Rock Selaginella, Rocky Mountain spikemoss Selaginella
Cupressaceae	*Juniperus communis* L. var. *depressa* Pursh	M, NAm	Common juniper, Dwarf juniper, Ground-cedar
Pinaceae	*Abies lasiocarpa* (Hook.) Nutt. var. *lasiocarpa*	BM, WNAm	Subalpine fir, Alpine fir
	Picea engelmannii Parry ex Englem.	BM, WNAm	Engelmann spruce
	Pinus contorta Dougl. ex Loud. var. *latifolia* Engelm. ex Wats.	BM, WNAm	Lodgepole pine
	Pinus flexilis James	BM, WNAm	Limber pine
Apiaceae	*Angelica grayi* (Coult. & Rose) Coult. & Rose	A, SRM	Gray's Angelica
	Conioselinum scopulorum (Gray) Coult. & Rose	M, WNAm	Hemlock parsley
	Ligusticum porteri Coult. & Rose var. *porteri*	M, WNAm	Porter lovage, Southern Ligusticum, Chuchupate, Osha
Asteraceae	*Achillea millefolium* L. var. *lanulosa* (Nutt.) Piper	GP, C	Western yarrow, Common yarrow, Common milfoil
	Agoseris aurantiaca (Hook.) Greene	BM, NAm	Orange-flowered mountain-dandelion, Orange false dandelion, Burnt-orange Agoseris, Orange Agoseris, Mountain dandelion
	Agoseris glauca (Pursh) Raf. var. *dasycephala* (T. & G.) Jeps.	M, WNAm	Pale Agoseris, Pale mountain dandelion, Pale false dandelion
	Anaphalis margaritacea (L.) Benth. & Hook.	M, NAm-Asi	Common pearly everlasting, Pearly everlasting
	Antennaria cf. *aromatica* Evert	AA, WNAm	
	Antennaria corymbosa E. Nels. [3]	M, WNAm	Meadow pussytoes, Plains pussytoes
	Antennaria media Greene	A, WNAm	Alpine pussytoes
	Antennaria microphylla Rydb.	M, NAm	Littleleaf pussytoes
	Antennaria rosea Greene	M, WNAm	Rose pussytoes, Rosey pussytoes, Pink pussytoes, Pink everlasting
	Antennaria umbrinella Rydb.	A, WNAm	Umber pussytoes, Mountain pussytoes
	Arnica cordifolia Hook.	M, NAm	Heart-leaved Arnica, Heartleaf Arnica
	Arnica latifolia Bong.	M, WNAm	Broadleaf Arnica
	Arnica mollis Hook.	BM, WNAm	Hairy Arnica
	Arnica parryi Gray var. *parryi*	M, WNAm	Nodding Arnica, Rayless Arnica, Parry Arnica
	Arnica rydbergii Greene	BM, WNAm	Rydberg Arnica
	Artemisia scopulorum Gray	A, RM	Alpine sagewort, Rocky Mountain sagewort
	Aster foliaceus Lindl. ex DC. var. *apricus* Gray	M, WNAm	Alpine leafybract Aster, Alpine leafy Aster
	Erigeron compositus Pursh var. *discoideus* Gray	BM, NAm	Dwarf mountain fleabane, Fernleaf daisy, Fernleaf fleabane, Compound-leaved flea-bane, Gold buttons, Cutleaf Erigeron, Cutleaf daisy
	Erigeron melanocephalus (A. Nels.) A. Nels.	A, SRM	Black-headed daisy, Alpine fleabane
	Erigeron peregrinus (Banks ex Pursh) Greene ssp. *callianthemus* (Greene) Cronq.	BM, WNAm	Peregrine fleabane, Subalpine daisy

Family	Botanical name [1]	Distribution [2]	Common name
	Erigeron pinnatisectus (Gray) A. Nels.	A, SRM	Pinnate fleabane, Pinnate daisy, Pinnate-leaf daisy
	Erigeron simplex Greene	A, WNAm	Alpine daisy, One-flowered fleabane, One-flowered daisy
	Erigeron ursinus D. C. Eat.	M, WNAm	Bear River fleabane
	Haplopappus pygmaeus (T. & G.) Gray	A, RM	Dwarf goldenweed, Pygmy Haplopappus, Alpine goldenweed
	Hieracium gracile Hook. var. *gracile*	A, NAm-SAm	Slender hawkweed, Alpine hawkweed
	Hymenoxys grandiflora (T. & G. ex Gray) Parker	A, RM	Old-man-of-the-mountain, Alpine sunflower, Graylocks actinea, Rydbergia
	Senecio canus Hook.	U, WNAm	Wooly groundsel, Prairie groundsel, Gray groundsel, Pursh Senecio, Gray ragwort
	Senecio crassulus Gray	BM, WNAm	Thickleaf groundsel
	Senecio dimorphophyllus Greene var. *dimorphophyllus*	M, NAm	Different groundsel
	Senecio fremontii T. & G. var. *blitoides* (Greene) Cronq.	A, SRM	Fremont groundsel, Rock groundsel
	Senecio integerrimus Nutt. var. *exaltatus* (Nutt.) Cronq.	GP, WNAm	Lambstongue groundsel
	Senecio streptanthifolius Greene	M, NAm	Manyface groundsel, Rocky Mountain butterweed
	Senecio triangularis Hook.	BM, WNAm	Arrowleaf groundsel, Arrowleaf butterweed
	Solidago multiradiata Ait. var. *scopulorum* Gray	M, NAm	Mountain goldenrod, Alpine goldenrod, Northern goldenrod, Rocky Mountain goldenrod
	Solidago parryi (Gray) Greene	A, WNAm	Parry goldenrod
	Solidago simplex Kunth	A, WNAm	Dwarf goldenrod, Coast goldenrod, Dwarf alpine goldenrod
	Taraxacum officinale Weber	U, Cos	Common dandelion
Boraginaceae	*Eritrichium nanum* (Vill.) Schrad. ex Gaudin var. *elongatum* (Rydb.) Cronq.	AA, WNAm	Alpine forget-me-not, Pale alpine forget-me-not, Low blue-eyes
	Mertensia ciliata (James ex Torr.) G. Don var. *ciliata*	BM, WNAm	Mountain bluebell, Broadleaf bluebell, Tall Mertensia
	Mertensia viridis (A. Nels.) A. Nels.	A, WNAm	Greenleaf bluebell, Green bluebell, Green Mertensia
Brassicaceae	*Arabis drummondii* Gray	M, NAm	Drummond rockcress
	Draba apiculata C. L. Hitchc.	M, WNAm	Pointed Draba
	Draba aurea Vahl ex Hornem.	AA, NAm	Golden Draba
	Draba cana Rydb.	AA, C	Lance-leaved Draba
	Draba crassifolia Grah.	AA, NAm-Eur	Rocky Mountain Draba, Thickleaved Draba
	Draba oligosperma Hook.	M, WNAm	Snowbank Draba
	Rorippa curvipes Greene var. *alpina* (Wats.) Stuckey	A, WNAm	Obtuseleaved yellowcress
	Thlaspi montanum L. var. *montanum*	A, C	Wild candytuft, Mountain pennycress, Alps pennycress
Callitrichaceae	*Callitriche palustris* L.	M, C	Spring water starwort, Vernal water-starwort
Caprifoliaceae	*Sambucus racemosa* L. ssp. *pubens* (Michx.) House var. *microbotrys* (Rydb.) Kearn. & Peeb.	M, WNAm	Scarlet elderberry, Red elderberry, Rocky Mountain red elder, Mountain red elderberry, Red-berried elder
Caryophyllaceae	*Arenaria congesta* Nutt. var. *congesta*	M, WNAm	Ballhead sandwort
	Cerastium arvense L.	BM, C-SAm-SAfr	Field mouse-ear, Field chickweed, Starry Cerastium, Meadow chickweed, Mouse-ear chickweed
	Minuartia obtusiloba (Rydb.) House	AA, NAm-Asi	Twinflower sandwort, Arctic sandwort
	Minuartia rubella (Wahlenb.) Hiern	AA, C	Boreal sandwort
	Paronychia pulvinata Gray	A, SRM	Rocky Mountain nailwort, Alpine nailwort, Cushion nailwort
	Sagina saginoides (L.) Karst.	AA, C	Arctic pearlwort, Alpine pearlwort
	Silene acaulis (L.) Jacq. var. *subacaulescens* (F. N. Williams) Fern. & St. John	AA, WNAm	Moss-pink, Moss campion, Moss Silene
	Silene drummondii Hook. var. *drummondii*	U, NAm	Drummond campion, Drummond catchfly, Drummonds cockle
	Silene drummondii Hook. var. *striata* (Rydb.) Bocq.	M, WNAm	Drummond campion, Drummond catchfly
	Silene parryi (Wats.) Hitchc. & Maguire	M, WNAm	Parry Silene
	Stellaria borealis Bigel. ssp. *borealis*	M, WNAm	Northern starwort, Northern stitchwort

Family	Botanical name [1]	Distribution [2]	Common name
	Stellaria calycantha (Ledeb.) Bong.	M, C	Northern starwort, Northern stitchwort
	Stellaria longipes Goldie var. *longipes*	BM, C	Long-stalked chickweed, Long-stalked starwort, Longstalk starwort, Long-stalked stitchwort
	Stellaria monantha Hult.	A, NAm	Longstalk starwort, Long-stalked chickweed
	Stellaria umbellata Turcz. ex Kar. & Kir.	A, NAm-Asi	Umbrella starwort, Umbellate starwort, Umbrella chickweed
Chenopodiaceae	*Chenopodium atrovirens* Rydb.	M, NAm	Dark goosefoot
Crassulaceae	*Sedum integrifolium* (Raf.) A. Nels. [3] ssp. *integrifolium*	AA, C	King's crown, Roseroot
	Sedum lanceolatum Torr. var. *lanceolatum*	A, WNAm	Lanceleaf stonecrop
	Sedum rhodanthum Gray	A. RM	Rose crown
Cyperaceae	*Carex aquatilis* Wahlenb. var. *aquatilis*	AA, C	Water sedge
	Carex atrata L. var. *erecta* Boott	M, WNAm	Blackscaled sedge, Blackened sedge
	Carex bipartita All.	AA, C	Two-parted sedge
	Carex canescens L. var. *canescens*	M, C	Silvery sedge, Pale sedge, Gray sedge
	Carex ebenea Rydb.	AA, WNAm	Ebony sedge, Black sedge
	Carex foetida All. [3] var. *vernacula* (Bailey) Kukenth.	A, NAm-Eur	Foetid sedge
	Carex geyeri Boott [3]	M, NAm	Elk sedge
	Carex haydeniana Olney	A, WNAm	Hayden sedge, Cloud sedge
	Carex illota Bailey	A, WNAm	Smallheaded sedge, Sheep sedge
	Carex microptera Mack. var. *microptera*	M, WNAm	Smallwing sedge
	Carex nardina Fries [3]	AA, C	Spikenard sedge
	Carex nelsonii Mack.	A, SRM	Nelson sedge
	Carex nigricans C. A. Mey.	A, NAm-Asi	Black alpine sedge
	Carex nova Bailey var. *nova*	BM, WNAm	New sedge, Black-spiked sedge
	Carex pachystachya Cham. ex Steud.	M, WNAm	Chamisso sedge, Thickheaded sedge
	Carex phaeocephala Piper	A, WNAm	Dunhead sedge, Brown-headed sedge
	Carex praeceptorum Mack.	A, WNAm	Teacher's sedge
	Carex pyrenaica Wahlenb.	A, C	Pyrenaean sedge
	Carex raynoldsii Dewey [3]	M, WNAm	Raynold sedge
	Carex rossii Boott	BM, NAm	Shortstemmed sedge, Ross sedge
	Carex rostrata Stokes [3] var. *rostrata*	M, C	Beaked sedge, Beaded sedge
	Carex rupestris All.	A, C	Rock sedge, Curly sedge
	Carex scopulorum Holm var. *scopulorum*	A, WNAm	Holm's Rocky Mountain sedge, Rock sedge
	Eleocharis pauciflora (Lightf.) Link	BM, C-SAm	Fewflowered spikerush
Ericaceae	*Arctostaphylos uva-ursi* (L.) Spreng. ssp. *uva-ursi* var. *u va-ursi*	M, C	Common bearberry, Kinnikinnick, Sandberry, Mealberry
	Arctostaphylos uva-ursi (L.) Spreng. ssp. *uva-ursi* var. *stipitata* (Packer & Denford) Dorn	M, NAm	Bearberry, Kinnikinnick, Bearberry manzanita, Sandberry
	Kalmia microphylla (Hook.) Heller var. *microphylla*	BM, WNAm	Alpine laurel, Alpine bog Kalmia, Swamp laurel
	Pyrola minor L.	M, C	Lesser wintergreen, Snowline Pyrola
	Vaccinium cespitosum Michx.	BM, NAm	Dwarf blueberry, Dwarf bilberry
	Vaccinium scoparium Leib. ex Cov.	BM, WNAm	Broom huckleberry, Grouse whortleberry, Grouseberry, Littleleaf whortleberry, Pink-fruited grouseberry
Fabaceae	*Lupinus argenteus* Pursh var. *argenteus*	M, WNAm	Silvery lupine, Common lupine
	Trifolium dasyphyllum T. & G.	A, WNAm	Alpine clover, Whiproot clover
	Trifolium parryi Gray	A, RM	Parry clover
Gentianaceae	*Gentiana algida* Pall.	AA, NAm-Asi	Arctic gentian, Whitish gentian
	Gentiana parryi Engelm.	M, WNAm	Parry gentian
	Gentianella amarella (L.) Boerner var. *amarella*	BM, C	Amarella, Northern annual gentian, Northern gentian
	Gentianopsis detonsa (Rottb.) Ma var. *elegans* (A. Nels.) N. Holmgren	M, C	Rocky Mountain fringed gentian
	Swertia perennis L.	M, C	Star gentian, Alpine bog Swertia, Swertia, Bog elkweed

Family	Botanical name [1]	Distribution [2]	Common name
Grossulariaceae	*Ribes lacustre* (Pers.) Poir. [3]	M, NAm	Swamp gooseberry, Swamp black current, Swamp black gooseberry
	Ribes montigenum McClat.	BM, WNAm	Mountain gooseberry, Alpine prickly current, Gooseberry current
Hydrophyllaceae	*Phacelia sericea* (Grah. ex Hook.) Gray var. *sericea*	A, WNAm	Purple pincushion, Purple fringe, Silky Phacelia, Silky scorpionweed
Juncaceae	*Juncus confusus* Cov.	M, WNAm	Colorado rush
	Juncus drummondii E. Mey.	A, WNAm	Drummond rush
	Juncus hallii Engelm. [3]	M, RM	Hall rush
	Juncus mertensianus Bong.	A, WNAm	Merten rush
	Juncus parryi Engelm.	A, WNAm	Parry rush
	Luzula multiflora (Ehrh.) Lej.	M, C	Many flowered woodrush, Hairy woodrush
	Luzula parviflora (Ehrh.) Desv.	BM, C	Millet woodrush, Smallflowered woodrush
	Luzula spicata (L.) DC.	A, C	Spiked woodrush
Liliaceae	*Erythronium grandiflorum* Pursh var. *grandiflorum*	M, WNAm	Glacier lily, Avalanche lily, Snow lily, Lambstongue troutlily, Yellow fawnlily, Dogtooth violet, Trout lily, Fawn lily, Adder's tongue
	Streptopus amplexifolius (L.) DC.	M, C	White mandarin twistedstalk, Cucumber-root, Clasping twisted-stalk, Clasping-leaved twisted stalk
	Zigadenus elegans Pursh	AA, NAm	White camas, Glaucus death camas, Mountain death camas, Elegant death camas
Onagraceae	*Epilobium anagallidifolium* Lam.	AA, C	Alpine willowherb, Alpine willowweed,, Pimpernel-leaved willowherb, Anagallis-leaved willowherb
	Epilobium angustifolium L. var. *angustifolium*	BM, C	Fireweed, Common fireweed, Fireweed willowherb, Giant willowherb, Blooming Sally
	Epilobium angustifolium L. var. *canescens* Wood	M, NAm	Fireweed, Narrow-leaved fireweed
	Epilobium ciliatum Raf. [3]	M, NAm-SAm-Asi	Common willowherb, Northern willowherb, Purpleleaf willowherb
	Epilobium clavatum Trel.	BM, C	Alpine willowherb
	Epilobium hornemannii Reichenb. ssp. *hornemannii*	BM, C	Hornemann willowherb
	Epilobium lactiflorum Hausskn.	M, NAm-Eur	Pale willowherb
	Epilobium saximontanum Hausskn.	M, NAm	Rocky Mountain willowherb
	Gayophytum decipiens Lewis & Szweyk.	M, WNAm	Deceptive groundsmoke, Deceptive Gayophytum
	Gayophytum diffusum T. & G. var. *strictipes* (Hook.) Dorn	M, WNAm	Bigflower groundsmoke, Spreading groundsmoke, Spreading Gayophytum, Baby's breath
Orchidaceae	*Platanthera dilatata* (Pursh) Lindl. ex Beck [3] var. *dilatata*	M, NAm	White bog orchid, Bog candle, White orchid, White Orchis, Tall white bog orchid
	Platanthera dilatata (Pursh) Lindl. ex Beck var. *albiflora* (Cham.) Ledeb.	M, WNAm	White bog orchid, Bog candle, White orchid, White Orchis
Poaceae	*Agropyron scribneri* Vasey	A, WNAm	Spreading wheatgrass, Scribner wheatgrass
	Agropyron trachycaulum (Link) Malte ex Lewis	BM, NAm	Slender wheatgrass, Bearded wheatgrass
	Agrostis humilis Vasey	M, WNAm	Alpine bentgrass, Snow bentgrass
	Agrostis scabra Willd. var. *scabra*	M, NAm-Asi	Ticklegrass, Hair grass, Rough bent, Winter bentgrass
	Agrostis thurberiana Hitchc.	A, WNAm	Thurber bentgrass, Thurber redtop, Thurber fescue
	Agrostis variabilis Rydb.	A, WNAm	Mountain bentgrass, Variant bentgrass, Mountain bent, Alpine redtop
	Bromus ciliatus L. [3]	M, NAm	Fringed brome
	Calamagrostis canadensis (Michx.) Beauv.	BM, C	Bluejoint reedgrass, Bluejoint, Canada reedgrass
	Calamagrostis purpurascens R. Br. var. *purpurascens*	AA, NAm-Asi	Purple reedgrass
	Danthonia intermedia Vasey	BM, NAm	Timber oatgrass, Timber Danthonia, Wild oat-grass
	Deschampsia atropurpurea (Wahlenb.) Scheele var. *latifolia* (Hook.) Scribn. ex Macoun	M, WNAm	Mountain hairgrass
	Deschampsia cespitosa (L.) Beauv. var. *cespitosa*	BM, C-Afr-NZ-Aus-NG	Tufted hairgrass

Family	Botanical name [1]	Distribution [2]	Common name
	Elymus glaucus Buckl. var. *glaucus*	M, NAm	Blue wildrye
	Festuca brachyphylla Schult. & Schult. ssp. *coloradensis* Frederiksen	AA, C	Alpine fescue
	Festuca saximontana Rydb. var. *saximontana*	M, NAm	Sheep fescue
	Phleum alpinum L. var. *alpinum*	AA, C-SAm	Alpine timothy, Mountain timothy
	Poa alpina L.	AA, C	Alpine bluegrass
	Poa arctica R. Br. var. *grayana* (Vasey) Dorn	A, C	Snowline bluegrass, Arctic bluegrass
	Poa cusickii Vasey var. *epilis* (Scribn.) C. L. Hitchc.	BM, WNAm	Skyline bluegrass
	Poa fendleriana (Steud.) Vasey	BM, NAm	Muttongrass, Mutton bluegrass
	Poa interior Rydb.	M, NAm	Inland bluegrass
	Poa leptocoma Trin.	M, WNAm-Asi	Bog bluegrass
	Poa nervosa (Hook.) Vasey var. *wheeleri* (Vasey) C. L. Hitchc.	M, WNAm	Wheeler bluegrass
	Poa pattersonii Vasey	AA, WNAm	Patterson bluegrass
	Poa reflexa Vasey & Scribn.	A, WNAm	Nodding bluegrass
	Poa rupicola Nash ex Rydb.	A, WNAm	Timberline bluegrass
	Poa secunda Presl var. *elongata* (Vasey) Dorn	M, NAm	Canby bluegrass
	Poa secunda Presl ex Scribn.) var. *incurva* (Scribn. & Williams	M, WNAm	Curly bluegrass Beetle
	Stipa lettermanii Vasey [3]	M, WNAm	Letterman needlegrass
	Trisetum spicatum (L.) Richt.	AA, C-SAm	Spike Trisetum, Spike oats
	Trisetum wolfii Vasey	M, WNAm	Wolf Trisetum
Polemoniaceae	*Phlox multiflora* A. Nels.	M, WNAm	Rocky Mountain Phlox, Flowery Phlox, Many flowered Phlox
	Phlox pulvinata (Wherry) Cronq.	A, WNAm	Cushion Phlox, Tufted Phlox
	Polemonium brandegei (Gray) Greene	BM, WNAm	Brandegee sky pilot, Brandegee Jacobsladder, Honey sky pilot, Pale sky pilot
	Polemonium viscosum Nutt. Polemonium, Viscid Jacobsladder	A, WNAm	Sky pilot, Sticky Polemonium, Skunkweed, Skunk
Polygonaceae	*Oxyria digyna* (L.) Hill	AA, C	Alpine sorrel, Mountain sorrel
	Polygonum bistortoides Pursh	A, WNAm	American bistort, Bistort
	Polygonum viviparum L.	AA, C	Viviparous bistort, Alpine bistort
	Rumex densiflorus Osterh.	M, WNAm	Dock, Sorrel
Portulacaceae	*Claytonia lanceolata* Pursh var. *lanceolata*	A, WNAm	Lanceleaf spring beauty, Western spring beauty
	Lewisia pygmaea (Gray) Robins. var. *pygmaea*	A, WNAm	Pygmy bitterroot, Least Lewisia
	Lewisia triphylla (Wats.) Robins.	M, WNAm	Threeleaf Lewisia
Primulaceae	*Androsace septentrionalis* L. var. *subulifera* Gray	M, WNAm	Pygmy flower rock jasmine, Small mountain rock jasmine, Northern Androsace
	Primula parryi Gray	A, WNAm	Parry primrose, Bog primrose
Ranunculaceae	*Anemone multifida* Poir. [3] var. *multifida*	M, NAm-SAm	Pacific Anemone, Cliff Anemone, Cutleaf Anemone, Globeflower, Cut-leaved Anemone
	Anemone patens L. var. *multifida* Pritz.	BM, NAm	Pasque flower, Wild Crocus, Easter flower
	Aquilegia coerulea James var. *coerulea*	M, WNAm	Colorado blue columbine, Colorado columbine, Rocky Mountain columbine
	Caltha leptosepala DC. var. *leptosepala*	A, WNAm	Elkslip marsh-marigold, Marsh marigold, Elk marsh marigold, White-flowered marsh-marigold
	Ranunculus alismifolius Geyer ex Benth. var. *montanus* Wats.	BM, WNAm	Plantainleaf buttercup, Mountain buttercup, Water-plantain buttercup
	Ranunculus eschscholtzii Schlecht. var. *eschscholtzii*	BM, NAm-Asi	Eschscholtz buttercup, Subalpine buttercup
	Ranunculus uncinatus D. Don ex G. Don [3]	M, WNAm	Little buttercup

Family	Botanical name [1]	Distribution [2]	Common name
	Trollius laxus Salisb. var. *albiflorus* Gray	BM, NAm	American globeflower, White globe-flower
Rosaceae	*Geum rossii* (R. Br.) Ser. var. *turbinatum* (Rydb.) C. L. Hitchc.	AA, NAm-Asi	Alpine avens, Ross avens
	Potentilla diversifolia Lehm. var. *diversifolia*	A, WNAm	Blueleaf cinquefoil, Varileaf cinquefoil
	Potentilla fruticosa L.	BM, C	Shrubby cinquefoil
	Potentilla nivea L.	AA, C	Snow cinquefoil
	Potentilla plattensis Nutt.	U, WNAm	Platte River cinquefoil, Platte cinquefoil, Nelson Potentilla
	Sibbaldia procumbens L.	AA, C	Creeping Sibbaldia
Salicaceae	*Populus tremuloides* Michx.	BM, NAm	Quaking aspen, Aspen
	Salix arctica Pall. [3] var. *petraea* Anderss.	A, C	Arctic willow
	Salix bebbiana Sarg. var. *bebbiana*	M, C	Bebb willow, Beaked willow
	Salix brachycarpa Nutt. var. *brachycarpa*	M, NAm	Barrenground willow, Short-fruited willow
	Salix cascadensis Ckll.	AA, WNAm	Cascade willow
	Salix glauca L. [3] var. *villosa* (Hook.) Anderss.	AA, C	Glaucous willow, Grayleaf willow, Blue-green willow
	Salix planifolia Pursh var. *monica* (Bebb) Schneid. ssp. *planifolia*	BM, NAm	Plainleaf willow, Planeleaved willow
Saxifragaceae	*Heuchera parvifolia* Nutt. ex T. & G.	M, WNAm	Littleleaf alumroot, Common alumroot
	Mitella pentandra Hook.	M, WNAm	Alpine mitrewort, Five star mitrewort
	Parnassia fimbriata Konig var. *fimbriata*	BM, WNAm	Rocky Mountain Parnassia, Fringed grass-of-Parnassus
	Saxifraga odontoloma Piper	BM, WNAm	Brook saxifrage
	Saxifraga rhomboidea Greene	M, WNAm	Diamondleaf saxifrage, Snowball saxifrage
	Saxifraga rivularis L. ssp. *hyperborea* (R. Br.) Dorn var. *debilis* (Engelm. ex Gray) Dorn	A, WNAm	Pygmy saxifrage, Weak saxifrage
Scrophulariaceae	*Castilleja rhexifolia* Rydb.	BM, WNAm	Splitleaf Indian paintbrush, Rhexialeaved paintbrush
	Castilleja sulphurea Rydb.	M, WNAm	Sulfur Indian paintbrush, Sulfur paintbrush
	Chionophila jamesii Benth.	A, SRM	James snowlover
	Pedicularis bracteosa Benth. var. *paysoniana* (Penn.) Cronq.	M, RM	Bracted lousewort
	Pedicularis groenlandica Retz.	AA, NAm	Little pink elephant, Elephantella, Elephant-head lousewort, Elephant's head
	Pedicularis parryi Gray	A, RM	Parry lousewort
	Pedicularis racemosa Dougl. ex Benth. var. *alba* (Penn.) Cronq.	M, WNAm	White flowered lousewort, Sickletop lousewort, Leafy lousewort, Parrot's beak
	Penstemon whippleanus Gray	M, WNAm	Whipple beardtongue, Whipple Penstemon
	Veronica wormskjoldii R. & S.	AA, NAm	American alpine speedwell, Wormskjold speedwell, Alpine speedwell
Violaceae	*Viola adunca* Sm.	BM, NAm	Mountain blue violet, Hoodedspur violet, Early blue violet, Blue violet, Western dog violet
	Viola palustris L.	BM, C	White marsh violet, Northern marsh violet, Marsh violet
	Viola praemorsa Dougl. ex Lindl.	M, WNAm	Astoria violet, Upland yellow violet

[1] *Plant names are based on those used at the Rocky Mountain Herbarium, University of Wyoming, Laramie, Wyoming.*

[2] *Abbreviations in the Geographic Distribution column are based on Cronquist et al. (1972, 1977, 1984, 1989), Gray (1880), Harrington (1964), Harshburger (1911), Hitchcock and Cronquist (1981), Hitchcock et al. (1955, 1959, 1961, 1964, 1969), Holm (1923), Hulten (1968), Hulten and Fries (1986a, 1986b, 1986c), Kearney and Peebles (1964), Komarkova (1979), Martin and Hutchins (1980, 1981), McGregor (1986), Moss (1983), Rydberg (1913, 1914a, 1914b, 1915a, 1915b, 1916, 1917, 1919, 1920, 1921), Weber (1965, 1967, 1987, 1990), Welsh (1974), and Welsh et al. (1987):*

A = alpine
AA = arctic-alpine
BM = boreal-montane
GP = Great Plains
M = montane
U = ubiquitous
C = circumpolar
C-Afr-NZ-Aus-NG = circumpolar - African - New Zealandian - Australian - New Guinean
C-SAm = circumpolar - South American
C-SAm-Afr-Ant = circumpolar - South American - African - Antarctican

C-SAm-Aus-NZ = circumpolar - South American - Australian - New Zealandian
C-SAm-SAfr = circumpolar - South American - South African
Cos = cosmopolitan
NAm = North American
NAm-Asi = North American - Asiatic
NAm-Eur = North American - European
NAm-SAm = North American - South American
NAm-SAm-Asi = North American - South American - Asiatic
RM = Rocky Mountain
SRM = Southern Rocky Mountain
WNAm = Western North American
WNam-Asi = Western North American - Asiatic

[3] *Taxon which was on Simmons' 1986 - 1987 list, but which was not collected in 1988, 1989, or 1990. All the other taxa field identified by Simmons were collected in 1988, 1989, or 1990.*

Appendix B.

Phytoplankton Species East Glacier, West Glacier, and Lost Lakes

R.G. Dufford
Fort Collins, Colorado

The species included in this list were collected from Lost Lake (L) and East Glacier Lake (EG) and West Glacier Lake (WG) and identified by Richard Dufford, Phychologist, in 1988. The collection is maintained by Mr. Dufford in Fort Collins, Colorado. Samples were collected as an integrated sample from a water column at the deepest section of the lake.

Taxon	Presence, 1988
Division Bacillariophyta (diatoms)	
Asterionella formosa	WG, L
Diatoma anceps	WG
Eunotia perpusilla	EG
Fragilaria crotonensis	L
F. pinnata	EG
F. vaucheriae	EG, WG
F. virescens	EG, L
Melosira italica	EG, L
M. lirata	EG, WG
Navicula sp.	L
N. minima	EG, WG
N. pupula var. *rectangularis*	EG
Neidium affine	EG
Nitzschia spp.	EG, WG
Pinnularia borealis	WG
P. maior	EG
P. mesolepta	EG, WG
Rhizosolenia eriensis	EG, WG, L
R. longiseta	EG
Stauroneis phoenicenteron	WG
Synedra sp.	EG
S. incisa	L
S. radians	WG
S. rumpens	L
Tabellaria fenestrata	EG, L
T. flocculosa	EG, WG, L
Division Chlorophyta (green algae)	
Monoraphidium griffithii	EG, WG, L
Ankistrodesmus falcatus var. *falcatus*	WG, L
Ankyra judayi	WG, L
Arthrodesmus (*Staurodesmus*) *incus*	EG
A. (*S.*) *ralfsii*	EG, WG, L
Botryococcus sp.	EG
Chlamydomonas spp.	EG, WG, L
C. angulosa	WG
Chlorella sp.	L
C. ellipsoidea	WG
C. vulgaris	EG, WG, L
Chlorococcum sp.	WG
Chlorogonium sp.	EG, WG, L
Coccomyxa minor	EG, WG, L
Cosmarium sp.	EG
Crucigeniella (Crucigenia) rectangularis	EG
Dictyosphaerium elegans	EG, WG, L

Taxon	Presence, 1988
D. pulchellum var. *minutum*	EG, WG, L
Elakatothrix viridis	EG, L
Euastrum elegans	EG
Gloeococcus sp.	EG, L
Gloeocystis sp.	L
Gloeotila sp.	EG, WG
Gloeotila contorta	WG, L
Gloeotila pelagica	EG, WG, L
Golenkinia radiata	EG
Gonium sp.	WG, L
Haematococcus lacustris	WG
Lagerheimia (*Chodatella*) *genevensis*	WG
Mesotaenium sp.	EG, WG
Micractinium pusillum	WG
Microspora sp.	L
Mougeotia sp.	L
Nephrocytium agardhianum	EG
Oocystis sp.	EG, L
O. pusilla	EG
Quadrigula sp.	WG
Scenedesmus sp.	L
S. ecornis	EG
S. quadricauda	WG
S. serratus	WG, L
Spondylosium planum	EG, WG, L
Staurastrum sp.	L
S. paradoxum	L
Teilingia sp.	EG, L
Tetraedron minimum	EG
Tetraspora lacustris	L
Tetrastrum elegans	WG
Ulothrix sp.	WG
Xanthidium sp.	EG
Zygnemopsis sp.	L
Division Chrysophyta (golden-brown algae)	
Bicosoeca sp.	L
Chromulina sp.	WG
Chrysocapsa planctonica	EG
Chrysococcus biporus	EG, WG, L
Chrysococcus rufescens	EG, WG
Chrysolykos skujae	EG, WG, L
Crysolykos planctonicus	EG, WG, L
Bitrichia (*Diceras*) *phaseolus*	EG, L
Dinobryon bavaricum	EG, WG, L
D. borgei	EG, WG, L
D. cylindricum	L
D. divergens	WG
D. sociale var. *americanum*	L
D. sertularia	WG
Kephyrion sp.	EG, L
K.boreale	EG, WG, L
K. cupuliforme	EG, WG
Mallomonas sp.	EG, WG, L
M. tonsurata	EG

Taxon	Presence, 1988
Ochromonas sp.	EG, WG
Pseudokephyrion entzii	EG, WG
Tribonema minus	WG
Division Cryptophyta (cryptophytes)	
Cryptomonas sp.	EG, WG
C. rostratiformis	L
C. marsonii	WG
Rhodomonas minuta	EG, WG
Division Cyanophyta (blue-green algae)	
Anabaena sp.	WG, L
A. affinis	WG
A. inaequalis	WG
A. wisconsinense	L
Aphanocapsa delicatissima	EG, L
A. elachista	EG, WG
A. elachista var. *conferta*	EG, WG, L
Aphanothece sp.	WG
A. nidulans	EG, WG
A. saxicola	EG, WG, L
Chroococcus dispersus	EG, WG, L
C. dispersus var. *minor*	EG, WG
C. limeticus	EG
C. minor	EG
Dactylococcopsis sp.	WG
D. acicularis	EG, WG, L
D. fascicularis	EG, WG, L
D. irregularis	WG, L
Leptolyngbya (*lyngbya*) *nana*	WG
Microcystis incerta	EG
Oscillatoria sp.	EG
O. angusta	EG, WG
O. angustissima	WG
O. limnetica	EG, WG, L
Phormidium sp.	EG
Planktolyngbya subtilis (*Lyngbya limnetica*)	WG
Pseudanabaena sp.	EG
Rhabdoderma sp.	EG
R. irregulare	EG, WG
R. sigmoidea	EG, WG
R. sigmoidea f. *minor*	WG
Rhabogloea ellipsoidea	WG
Synechococcus lineare	EG
Division Euglenophyta (euglenoids)	
Euglena sp.	WG, L
E. gracilis	WG
Division Pyrrophyta (dinoflagellates)	
Peridinium cinctum	EG, L
P. inconspicuum	EG, WG, L
P. pusillum	EG, WG, L
P. willei	EG, WG, L

Appendix C.

GLEES Macroinvertebrates

B.C. Kondratieff
Department of Entomology, Colorado State University
Fort Collins, Colorado

This Appendix identifies macroinvertebrate species found in streams and lakes at GLEES during a preliminary qualitative survey conducted in the summer of 1988 by Dr. Boris Kondratieff. The littoral zones of each lake and each stream were sampled by hand-picking and with a triangle net. Insect voucher specimens are maintained in the Gillette Entomological Museum at Colorado State University in Fort Collins, CO. Asterisked species were found in East and/or West Glacier Lakes. Other species are not identified by location at GLEES, but this information is available from the voucher collection.

- ANNELIDA (worms)
  - Class Oligochaeta (Aquatic worms)
    - Lumbriculida
      - Lumbriculidae
        - *Limnodrilus* sp.
- ARTHROPODA
  - Class Hexapoda (Insects)
    - Ephemeroptera (Mayflies)
      - Baetidae
        - *Acentrella insignificans* McDunnough
        - *Baetis bicaudatus* Dodds
        - *Baetis tricaudatus* Dodds
      - Siphlonuridae
        - *Ameletus* sp.
      - Heptageniidae
        - *Cinygmula mimus* (Eaton)
        - *Epeorus longimanus* (Eaton)
        - *Epeorus* sp.
        - *Rhithrogena* sp.
      - Leptophlebiidae
        - *Paraleptophlebia debilis* (Walker)
      - Ephemerellidae
        - *Drunella coloradensis* (Dodds)
        - *Ephemerella infrequens* (McDunnough)
    - Plecoptera (Stoneflies)
      - Nemouridae
        - *Malenka flexura* (Claassen)
        - **Nemoura arctica* (Esben-Petersen)
        - **Podmosta delicatula* (Claassen)
        - *Prostoia besametsa* (Ricker)
        - *Zapada cinctipes* (Banks)
      - Capniidae
        - **Capnia confusa* (Claassen)
        - *Utacapnia poda* (Nebeker and Gaufin)
      - Leuctridae
        - *Paraleuctra vershina* (Gaufin and Ricker)
      - Taeniopterygidae
        - *Taenionema nigripenne* (Banks)
      - Pteronarcyidae
        - *Pteronarcella badia* (Hagen)
      - Perlodidae
        - *Isoperla quinquepunctata* (Banks)
        - *Isoperla fulva* (Claassen)
        - *Megarcys signata* (Hagen)
        - *Skwala americana* (Klapalek)
      - Perlidae
        - *Hesperoperla pacifica* (Banks)
      - Chloroperlidae
        - *Alloperla severa* (Hagen)
        - *Sweltsa borealis* (Banks)
        - *Sweltsa coloradensis* (Banks)
        - *Sweltsa lamba* (Needham and Claassen)
        - *Triznaka signata* (Banks)
    - Trichoptera (Caddisflies)
      - Brachycentridae
        - *Amiocentrus aspilus* (Ross)
      - Glossosomatidae
        - *Glossosoma parvulum* Banks
        - *Glossosoma ventrale* Banks
      - Helicopsychidae
        - *Helicopsyche borealis* (Hagen)
      - Hydropsychidae
        - *Arctopsyche grandis* (Banks)
        - *Hydropsyche cockerelli* Banks
      - Hydroptilidae
        - *Hydroptila xera* Ross
      - Lepidostomatidae
        - *Lepidostoma cascadense* Milne
        - *Lepidostoma ormea* Ross
      - Limnephilidae
        - *Allomyia chama* (Denning)
        - *Allomyia tripunctata* (Banks)
        - **Apatania zonella* (Zetterstedt)
        - *Asynarchus nigriculus* (Banks)
        - *Chyranda centralis* (Banks)
        - *Dicosmoecus atripes* (Hagen)
        - *Ecclisomyia maculosa* Banks
        - *Grammotaulius lorettae* Denning
        - **Hesperophylax occidentalis* (Banks)
        - *Limnephilus abbreviatus* Banks
        - **Limnephilus coloradensis* (Banks)
        - *Limnephilus externus* (Hagen)
        - **Limnephilus picturatus* McLachlan
        - *Oligophlebodes minutus* (Banks)

Onocosmoecus unicolor (Banks)
Psychoglypha subborealis (Banks)
Philopotamidae
Dolophilodes aequalis (Banks)
Psychomyiidae
Psychomyia flavida Hagen
Rhyacophilidae
Rhyacophila brunnea Banks
Rhyacophila angelita Banks
Rhyacophila coloradensis Banks
Rhyacophila hyalinata Banks
Rhyacophila pellisa Ross
Rhyacophila verrula Milne
Diptera (Flies)
Tipulidae
Dicranota sp.
Chironomidae
Tanypodinae
Ablabesmyia sp.
Chironominae
Chironomus sp.
Micropsectra sp.
Diamesinae
Diamesa sp.
Pseudodiamesa sp.
MOLLUSCA (Snails and Clams)
Pelecypoda (Clams)
Sphaeriidae
Sphaerium sp.

* = In Glacier Lakes.

Appendix D

The Map Units for GLEES Soil Survey Area

R.W.E. Hopper and P.M. Walthall
Agronomy Department, Colorado State University
Fort Collins, Colorado

The soils map of GLEES watersheds is shown in chap. 5, fig. 5.1. The following map units are described in this Appendix:

1. Typic Cryoboralfs - Dystric Cryochrepts complex
2. Typic Cryoboralfs complex
3. Dystric Cryochrepts - Lithic Cryochrepts complex
4. Dystric Cryochrepts complex
5. Dystric Cryochrepts - Rubbleland, quartzite complex

5m. Dystric Cryochrepts - Rubbleland, mafic intrusives complex

6. Typic Cryumbrepts - Dystric Cryochrepts complex
7. Rock Outcrop, quartzite - Dystric Cryochrepts - Lithic Cryochrepts complex

7m. Rock Outcrop, mafic igneous intrusives - Dystric Cryochrepts - Lithic Cryochrepts complex

8. Histic Cryaquepts - Aeric Cryaquepts complex
9. Rubbleland
10. Rubbleland - Rock Outcrop complex
11. Permanent Snowfields and Icefields
12. Typic Cryorthents - Rubbleland complex
13. Dystric Cryochrepts - Lithic Cryumbrepts - Rock Outcrop complex

W. Water

Detailed profile descriptions of the soil types identified in the map units are found in Appendix E.

1. Typic Cryoboralfs - Dystric Cryochrepts complex, 5–45% slopes

This complex consists of deep, well-drained soils on gently sloping to moderately steep slopes. The soils are developed in a relatively thin veneer of well-graded glacial till and nivation debris on summit, shoulder, backslope and footslope positions of moraine-like and kame terrace landforms of Neoglacial and Pinedale age. Resistant bedrock controls the location and form of structural benches that impart a stairstep backslope profile to these landforms. Outcrops of both quartzite and mafic igneous intrusives, high in actinolite and epidote, occur within delineations of this map unit. The map unit is primarily forested. Small areas of herbaceous vegetation occur throughout and are associated with late-melting snow accumulations.

Typic Cryoboralfs (loamy-skeletal, mixed) make up about 65% of the map unit. Dystric Cryochrepts (loamy-skeletal, mixed) make up about 25% of the unit. Included in the mapping are small areas of the named components on slopes that are less than 5% and greater than 45%, both quartzite and mafic igneous Rock Outcrop. In addition, Lithic Cryochrepts (loamy-skeletal, mixed) associated with the rock outcrops and Typic Cryumbrepts (loamy-skeletal, mixed) associated with small areas of late-melting snow accumulations may be found. These inclusions make up about 10% of the total extent of the map unit in the survey area.

The Typic Cryoboralfs are deep, are well-drained, and have moderate to moderately rapid permeability. They are formed in glacial till and are typically associated with gently sloping to moderately steep portions of benches on the backslopes and with shoulder and summit positions on the associated landform. Slopes are 5–30%, 10–20 m in length, and plane or slightly convex in shape. In most areas surface runoff is limited due to the forest litter layer at the surface. The erosion hazard is low. The majority of roots are located in the upper 60 cm of the profile with lesser amounts of very fine roots extending to 100 cm or more. Most areas of these soils support subalpine forest and/or krummholz vegetation.

In a representative profile of these Typic Cryoboralfs the surface layer is a black to very dark grayish-brown peat, composed of forest litter in various states of decomposition about 3 cm thick. The surface mineral horizon is a yellowish-brown or brown to very pale brown, very gravelly loam about 11 cm thick. The subsoil is a brown to light brown, extremely gravelly, silty clay loam about 20 cm thick over a yellowish-brown, dark-brown, and strong brown very cobbly sandy loam to 100 cm or more. Some areas of these soils are very or extremely cobbly, stony, or bouldery throughout the profile.

Detailed profile descriptions and associated selected physical and chemical laboratory data for representative soils are those provided for pedons WYGL001, WYGL002, WYGL005, and WYGL016.

The Dystric Cryochrepts are deep, well-drained, and have moderate to moderately rapid permeability. They are formed in glacial till and nivation debris and are typically associated with moderately steep slopes between benches on the backslopes of the associated landform. Slopes are 30–45%, 10–20 m in length, and plane or slightly convex in shape. Surface runoff is limited

due to the forest litter layer at the surface in most areas. The erosion hazard is low. The majority of roots are located in the upper 20 cm of the profile with lesser amounts of very fine roots extending to 100 cm or more. Most areas of these soils support subalpine forest and/or krummholz vegetation.

In a representative profile of these Dystric Cryochrepts, the surface layer is a very dark gray to very dark grayish-brown peat composed of forest litter in various states of decomposition about 4 cm thick. The surface mineral horizon is a brown to pale brown gravelly loam about 9 cm thick. The subsoil is a yellowish-brown and pink to very pale brown, very gravelly loam about 34 cm thick over a brown to pink, very cobbly to extremely gravelly loam to 105 cm or more. Some areas of these soils are very or extremely cobbly, stony, or bouldery thoughout the profile.

Samples specific for this map unit were not collected. However, detailed profile descriptions and selected physical and chemical laboratory data are provided for WYGL006, WYGL007, and WYGL015, which are morphologically similar soils.

2. Typic Cryoboralfs complex, 5–20% slopes

This complex consists of deep, well-drained soils on gently sloping to moderately steep slopes. The soils are developed in a relatively thin veneer of well-graded glacial till and nivation debris on summit, shoulder, backslope, and footslope positions of glacial moraines and moraine-like landforms of Neoglacial and Pinedale age. The map unit is sparsely forested with large open areas of herbaceous vegetation.

The principal components of this map unit are both Typic Cryoboralfs (loamy-skeletal, mixed) that differ in the amount of cobblestones and stones on the surface. Very stony Typic Cryoboralfs (loamy-skeletal, mixed) make up about 75% of the map unit. Stony Typic Cryoboralfs (loamy-skeletal, mixed) make up about 20% of the map unit. Included in the mapping are small areas of Dystric Cryochrepts (loamy-skeletal, mixed) and Typic Cryumbrepts (loamy-skeletal, mixed) associated with small areas of late-melting snow accumulations. These inclusions make up about 5% of the total extent of the map unit in the survey area.

These Typic Cryoboralfs are deep, well-drained, and have moderate to moderately rapid permeability. They are formed in glacial till and are typically associated with gently sloping to sloping footslope, backslope, shoulder, and summit positions. Slopes are 5–20%, 10–20 m in length, and plane or slightly convex in shape.

Surface runoff is medium to rapid; however, erosion is slight to moderate due to the amount of rock fragments on the surface. The majority of roots are located in the upper 60 cm of the profile with lesser amounts of very fine roots exending to 100 cm or more. The species composition of the vegetation supported by the soils of this map unit is variable and complex. Most areas of the very stony phase of the Typic Cryoboralfs support open herbaceous vegetation. Most areas of the stony phase of the Typic Cryoboralfs support subalpine forest and/or krummholz.

The Typic Cryoboralfs that compose the principal components of this map unit are morphologically similar but differ in the amount of cobblestones, stones, and boulders at the surface and by the presence or absence of a forest litter layer. A typical profile of the stony Typic Cryoboralfs is similar to the Cryoboralfs described for map unit 1, having a surface layer that is a black to very dark grayish-brown peat composed of forest litter in various states of decomposition about 3 cm thick. The surface mineral horizon is a yellowish-brown or brown to very pale brown, very gravelly loam about 11 cm thick. The subsoil is a brown to light brown, extremely gravelly, silty clay loam about 20 cm thick over a yellowish-brown, dark brown and strong brown, very cobbly sandy loam to 100 cm or more.

The very stony Typic Cryoboralfs exhibit morphological characteristics similar to those described above, but lack a surface forest litter layer. In these soils the surface layer is a dark gray to very dark grayish-brown, very stony loam.

Samples specific for this map unit were not collected. However, detailed profile descriptions and associated selected physical and chemical laboratory data are provided for similar soils—pedons WYGL001, WYGL002, WYGL005, and WYGL016.

3. Dystric Cryochrepts - Lithic Cryochrepts complex, 5–25% slopes

This complex consists of moderately deep and shallow, well-drained soils on gently sloping to moderately steep slopes. These soils are developed in nivation debris and residuum on summits and shoulders of subalpine and alpine ridges. The soils of this map unit primarily support herbaceous alpine vegetation. Small areas of krummholz vegetation occur throughout.

Dystric Cryochrepts (loamy-skeletal, mixed) make up about 55% of the map unit. Lithic Cryochrepts (loamy-skeletal, mixed) make up about 35% of the unit. Included in the mapping are small areas of both quartzite and mafic igneous Rock Outcrop and Rubbleland (talus), Typic Cryorthents (loamy-skeletal, mixed) at higher elevations, and Typic Cryoboralfs (loamy-skeletal, mixed) at lower elevations. The latter are developed in isolated pockets of well-graded glacial till. These inclusions make up about 10% of the total extent of the map unit in the survey area.

The Dystric Cryochrepts are moderately deep, well-drained, and have moderate to rapid permeability. They are formed in nivation debris and coarse residuum. Slopes are 5–25%, 10–35 m in length, and plane or slightly convex in shape. Surface runoff is medium to rapid. The erosion is slight to moderate due to the large amount of gravel and cobblestones on the surface. The majority of roots are located in the upper 30 cm of the profile with lesser amounts of very fine roots extending to the bedrock contact at less than 100 cm. Most areas of these soils support open alpine vegetation.

In a representative profile of these Dystric Cryochrepts, the surface layer is a very dark grayish-brown to yellowish-brown, extremely gravelly, sandy loam about 12 cm thick. The subsoil is a brown to reddish-yellow, extremely gravelly, coarse, sandy loam about 18 cm thick over a yellowish-brown to very pale brown, extremely stony, fine sandy loam about 17 cm thick. The substratum is a yellow to very pale brown, extremely stony, fine sandy loam about 12 cm thick, and is underlain by quartzite bedrock at about 59 cm.

The detailed profile description and associated selected physical and chemical laboratory data for WYGL003 are representative of this soil.

The Lithic Cryochrepts are shallow, well-drained and have moderate to rapid permeability. They are formed in nivation debris and coarse residuum. Slopes are 5–25%, 10–35 m in length, and plane or slightly convex in shape. Surface runoff is medium to rapid. The erosion is slight to moderate due to the large amount of gravel and cobblestones on the surface. The majority of roots are located in the upper 30 cm of the profile with lesser amounts of very fine roots extending to the bedrock contact at less than 50 cm. Most areas of these soils support open alpine vegetation.

The Lithic Cryochrepts typically exhibit morphological characteristics similar to those described above for the Dystric Cryochrepts, but the depth to hard bedrock is less than 50 cm. Specific samples of the soils in this map unit were not collected. However, the detailed profile description and selected physical and chemical laboratory data for WYGL003 would be pertinent.

4. Dystric Cryochrepts complex, 5–25% slopes

This complex consists of deep, well-drained soils developed in colluvium and nivation debris on gently sloping to moderately steep backslope and footslope positions of mountain sides and ridges. The map unit is primarily forested with open areas of herbaceous vegetation.

The principal components of this map unit are both Dystric Cryochrepts (loamy-skeletal, mixed) that differ in the amount of cobblestones and stones on the surface. Stony Dystric Cryochrepts (loamy-skeletal, mixed) make up about 60% of the map unit. Very stony Dystric Cryochrepts (loamy-skeletal, mixed) make up about 30% of the map unit. Included in the mapping are small areas of Lithic Cryochrepts (loamy-skeletal, mixed) and Rock Outcrop. These inclusions make up about 10% of the total extent of the map unit within the survey area.

The stony Dystric Cryochrepts are deep, are well-drained, and have moderate to moderately rapid permeability. Slopes are 5–25%, 10–20 m in length, and plane or slightly convex in shape. Surface runoff is limited due to the forest litter layer at the surface in most areas. The erosion hazard is low. The majority of roots are located in the upper 30 cm of the profile with lesser amounts of very fine roots extending to 105 cm or more. Most areas of these soils support forest vegetation.

In a representative profile of these Dystric Cryochrepts the surface layer is a very dark gray to very dark grayish-brown peat composed of forest litter in various states of decomposition about 4 cm thick. The surface mineral horizon is a brown to pale brown, gravelly loam about 9 cm thick. The subsoil is a yellowish-brown and pink to very pale brown, very gravelly loam about 34 cm thick over a brown to pink, very cobbly to extremely gravelly loam to 105 cm or more. Some areas of these soils are very or extremely cobbly, stony, or bouldery throughout the profile.

Detailed profile descriptions and associated selected physical and chemical laboratory data of representative soils are those for WYGL006 and WYGL007. These soils are also morphologically similar to WYGL015 except that they lack the accumulation of clay (argillic horizon) in the solum.

The very stony Dystric Cryochrepts are deep, well-drained, and have moderate to moderately rapid permeability. Slopes are 5–25%, 10–30 m in length, and plane or slightly convex in shape. Surface runoff is medium to rapid. However, the erosion hazard is slight to moderate due to the high amounts of rock fragments at the soil surface. The majority of roots are located in the upper 30 cm with lesser amounts of very fine roots extending to about 90 cm. Most areas of these soils support open herbaceous vegetation. Scattered individual trees occur within these areas.

In a representative profile of the very stony Dystric Cryochrepts, the surface layer is a very dark gray and dark brown to very dark grayish-brown, extremely cobbly loam about 15 cm thick. The subsoil is a brown to very pale brown, extremely cobbly loam about 18 cm thick over a brown and yellowish-brown to very pale brown, extremely cobbly loam about 22 cm thick. The substratum is an olive brown and dark yellowish-brown to light yellowish-brown, extremely cobbly loam to 108 cm or more.

A detailed profile description and associated selected physical and chemical laboratory data of a representative soil are those for WYGL015.

5. Dystric Cryochrepts - Rubbleland, quartzite complex, 25–45% slopes

This complex consists of deep, well-drained soils and talus on moderately steep and steep portions of backslopes and shoulders of mountain sides and ridges. The map unit is sparsely forested, mostly krummholz, with open areas of herbaceous vegetation and talus.

Dystric Cryochrepts (loamy-skeletal, mixed), make up about 60% of the map unit. Rubbleland makes up about 30% of the unit. Included in the mapping are small areas of Lithic Cryochrepts (loamy-skeletal, mixed) Typic Cryumbrepts (loamy-skeletal, mixed), and quartzite Rock Outcrop. These inclusions make up about 10% of the total extent of the map unit within the survey area.

The Dystric Cryochrepts are deep, are well-drained, and have moderate to rapid permeability. They are formed in colluvium and nivation debris primarily from the local quartzite bedrock. Slopes are 25–45%, 10–30 m in length, and plane or slightly concave in shape.

Surface runoff is medium to rapid. However, the erosion hazard is low to moderate due to the high amount of rock fragments on the soil surface and to relatively thick vegetation. The majority of roots are located in the upper 30 cm of the profile with lesser amounts of very fine roots extending to about 90 cm. Most areas of these soils support open vegetation. Scattered individual trees occur within these areas.

In a representative profile of these Dystric Cryochrepts the surface layer is a very dark gray and dark brown to very dark grayish-brown, extremely cobbly loam about 15 cm thick. The subsoil is a brown to very pale brown, extremely cobbly loam about 18 cm thick over a brown and yellowish-brown to very pale brown, extremely cobbly loam about 22 cm thick. The substratum is an olive brown and dark yellowish-brown to light yellowish-brown, extremely cobbly loam to 108 cm or more.

Samples specific for this map unit were not collected. However, detailed profile descriptions and associated selected physical and chemical laboratory data for morphologically similar soils are provided by those for WYGL006, WYGL007, and WYGL015.

Rubbleland, quartzite consists of rock talus on moderately steep and steep slopes. Little or no fine earth material fills the interstices between the cobblestones, stones, and boulders composing the talus. These areas do not support vegetation. However, small, isolated areas having thin deposits of soil do support sparse herbaceous vegetation. Little or no surface runoff is experienced from these areas although snow meltwater passes freely downslope through this material.

5m. Dystric Cryochrepts - Rubbleland, mafic intrusives complex, 25–45% slopes

This map unit is similar to map unit 5, but differs in that it is associated with mafic igneous dikes. These mafic igneous rocks are high in actinolite and epidote (Rochette 1987).

Dystric Cryochrepts (loamy-skeletal, mixed), make up about 60% of the map unit. Rubbleland makes up about 30% of the unit. Included in the mapping are small areas of Lithic Cryochrepts (loamy-skeletal, mixed), Dystric Cryochrepts (fine-loamy, mixed), Typic Cryumbrepts (loamy-skeletal, mixed), Typic Cryorthents (loamy-skeletal, mixed), and mafic igneous Rock Outcrop. These inclusions make up about 10% of the total extent of this map unit within the survey area.

The Dystric Cryochrepts of this map unit are similar to those described as occurring in map unit 5 with respect to morphology, setting, surface runoff, erosion potential, and vegetation, but differ by being developed in colluvium and nivation debris from mafic igneous intrusives and by containing higher relative amounts of these rock types as fragments throughout the soil profile.

Samples specific for this map unit were not collected. However, detailed profile descriptions and associated selected physical and chemical laboratory data for morphologically similar soils are pedons WYGL006 and WYGL015. Moderately deep, well-drained Dystric Cryochrepts (fine-loamy, mixed) developed in weathered residuum from the mafic intrusives are included in the map unit. A representative profile description together with selected physical and chemical laboratory data for this type of soil are provided by pedon WYGL012.

Rubbleland, mafic igneous intrusives, consists of rock talus on moderately steep and steep slopes. Little or no fine earth material fills the interstices between the cobblestones, stones, and boulders composing the talus. These areas do not support vegetation. However, small, isolated areas having thin deposits of soil do support sparse herbaceous vegetation. Little or no surface runoff is experienced from these areas although snow meltwater freely passes downslope through this material.

6. Typic Cryumbrepts - Dystric Cryochrepts complex, 0–20% slopes

This complex consists of deep, well-drained soils on nearly level to sloping footslopes and toeslopes of mountain sides and on structural benches in mid-backslope positions. The soils of this map unit primarily support open meadow vegetation. The margins of these areas may be sparsely forested. These areas are associated with significant pocket gopher activity and commonly have large accumulations of snow that persist well into the summer growing season.

Typic Cryumbrepts (loamy-skeletal, mixed) make up about 60% of the map unit. Dystric Cryochrepts (loamy-skeletal, mixed) make up about 30% of the map unit. Included in the mapping are small areas of Aquic Cryumbrepts (loamy-skeletal, mixed) and Cryaquepts. These inclusions make up about 10% of the total extent of the map unit in the survey area.

The Typic Cryumbrepts are deep, are well-drained, and have moderately slow to moderately rapid permeability. They are formed in water-worked colluvium and are typically associated with nearly level to gently sloping portions of footslope and toeslope positions. They tend to be more centrally located in a delineation. Slopes are 0–10%, 10–30 m in length, and plane or slightly convex in shape. Surface runoff is slow to medium and the erosion hazard is slight. The majority of roots are located in the upper 30 cm of the profile with lesser amounts of very fine roots extending to about 90 cm. Most of these soils support open alpine meadow and/or wet meadow vegetation.

In a representative profile of these Typic Cryumbrepts, the surface layer is a dark brown to brown silt loam about 9 cm thick. The subsoil is a dark brown to yellowish-brown silt loam about 21 cm thick over a brown to light yellowish-brown, very stony silt loam about 29 cm thick. The substratum is a yellowish-brown to very pale brown, extremely cobbly, sandy loam to 108 cm or more.

Detailed profile descriptions and associated selected physical and chemical laboratory data of representative soils are those provided for pedons WYGL009 and WYGL010.

The Dystric Cryochrepts are deep, well-drained, and have moderate to moderately rapid permeability. They are formed in colluvium and are typically associated

with nearly level to sloping portions of footslope and toeslope positions occurring throughout the unit. They tend to occur at significant slope breaks and near the margins of delineations, particularly along forest-meadow boundaries. Slopes are 5–20%, about 10 m in length, and plane in shape. Surface runoff is slow to medium and the erosion hazard is slight to moderate. The majority of roots are located in the upper 30 cm with lesser amounts of very fine roots extending to about 90 cm. Most areas of these soils support open herbaceous vegetation.

A typical profile of the Dystric Cryochrepts in this unit is similar to that described for the very stony phase in map unit 4, having a surface layer that is a very dark gray and dark brown to very dark grayish-brown, extremely cobbly loam about 15 cm thick. The subsoil is a brown to very pale brown, extremely cobbly loam about 18 cm thick over a brown and yellowish-brown to very pale brown, extremely cobbly loam about 22 cm thick. The substratum is an olive brown and dark yellowish-brown to light yellowish-brown, extremely cobbly loam to 108 cm or more.

Samples specific to this map unit were not collected. A detailed profile description and associated selected physical and chemical laboratory data of a morphologically similar soil are those provided for pedon WYGL015.

The included soils having high water tables are represented by pedon WYGL011.

7. Rock Outcrop, quartzite - Dystric Cryochrepts - Lithic Cryochrepts complex, 15–45% slopes

This complex consists of quartzite bedrock outcrops and deep and shallow, well-drained soils developed in colluvium and nivation debris on sloping to steep summits and shoulders of mountain sides and ridges. The soils of this map unit primarily support subalpine forest and krummholz vegetation. Small areas of open herbaceous vegetation occur throughout.

Rock Outcrop, quartzite makes up about 35% of the map unit. Dystric Cryochrepts (loamy-skeletal, mixed) make up about 30% of the map unit. Lithic Cryochrepts (loamy-skeletal, mixed) make up about 25% of the map unit. Included in the mapping are small areas of the named components on slopes that are less than 15% and greater than 45%, Typic Cryumbrepts (loamy-skeletal, mixed) and Rubbleland. These inclusions make up about 10% of the total extent of the map unit within the survey area.

Outcrops of quartzite bedrock are associated with sloping to steep structural benches. Slopes are typically 15–45%, but may be greater or lesser for short slope lengths. Slope shape is variable and complex. The vegetation of these areas is limited to lichens and mosses.

The Dystric Cryochrepts are deep, are well-drained soils associated with gently sloping to moderately steep slopes between bedrock-controlled benches. They have moderate to rapid permeability. Slopes are 15–45%, 10–25 m in length, and plane or slightly concave in shape. Surface runoff is limited due to the forest litter layer at the surface in most areas. The erosion hazard is low. The majority of roots are located in the upper 30 cm of the profile with lesser amounts of very fine roots extending to 105 cm or more. Most areas of these soils support subalpine forest vegetation.

A typical profile of the Dystric Cryochrepts in this unit is similar to those described for map unit 4, having a surface layer that is a very dark gray to very dark grayish-brown peat composed of forest litter in various states of decomposition about 4 cm thick. The surface mineral horizon is a brown to pale brown, gravelly loam about 9 cm thick. The subsoil is a yellowish-brown and pink to very pale brown, very gravelly loam about 34 cm thick over a brown to pink, very cobbly to extremely gravelly loam to 105 cm or more. In some profiles a surface forest litter layer is absent. In these cases the surface layer is a very dark to dark grayish-brown, extremely gravelly silt loam.

Samples specific to this map unit were not collected. However, detailed profile descriptions and associated selected physical and chemical laboratory data of morphologically similar soils are those provided for pedons WYGL006 and WYGL007. These soils are also morphologically similar to pedon WYGL005 but lack the accumulation of clay (argillic horizon) in the subsoil.

The Lithic Cryochrepts are shallow, well-drained soils on sloping to moderately steep slopes. They have moderate to rapid permeability. Fracturing in the quartzite bedrock is extensive and deep in most areas within the survey area. Consequently, these Lithic Cryochrepts occur in close association with the bedrock outcrop and are not disseminated throughout the unit. Slopes are 15–45%, about 10 m in length, and plane or slightly convex in shape. Surface runoff is limited due to the forest litter layer at the surface in most areas and the erosion hazard is low. The majority of roots are located in the upper 20 cm of the profile with lesser amounts of very fine roots extending to the bedrock contact at less than 50 cm. Most areas of these soils support subalpine forest vegetation.

These soils are similar to the Dystric Cryochrepts described above but differ by being less than 50 cm to hard bedrock. Samples of these soils were not collected. Their morphology and their physical and chemical characteristics are similar to those described for the Dystric Cryochrepts in this unit except for depth.

7m. Rock Outcrop, mafic igneous intrusives - Dystric Cryochrepts - Lithic Cryochrepts complex, 15–45% slopes

This mapping unit is similar to map unit 7, but differs in that it is associated with mafic igneous dikes. These mafic rocks contain large amounts of actinolite and epidote (Rochette 1987).

Rock Outcrop, mafic igneous intrusives makes up about 35% of the map unit. Dystric Cryochrepts (loamy-skeletal, mixed) make up about 30% of the map unit. Lithic Cryochrepts (loamy-skeletal, mixed) make up

about 25% of the map unit. Included in the mapping are small areas of the named components on slopes that are less than 15% and greater than 45%, Dystric Cryochrepts (fine-loamy, mixed), Typic Cryumbrepts (loamy-skeletal, mixed), and Rubbleland. These inclusions make up about 10% of the total extent of the map unit within the survey area.

Outcrops of the mafic igneous dikes are associated with structural benches. Slopes are typically 15–45%, but may be greater or lesser for short slope lengths. Slope shape is variable and complex. The vegetation of these areas is limited to lichens and mosses.

The Dystric and Lithic Cryochrepts of this unit are similar to those described as occurring in map unit 7 with respect to morphology, setting, surface runoff, erosion potential, and vegetation; but they differ by being developed in colluvium and nivation debris from mafic igneous intrusives and by containing higher relative amounts of these rock types as fragments throughout the profile.

Samples specific for this map unit were not collected. However, detailed profile descriptions and associated selected physical and chemical laboratory data of morphologically similar soils are those provided for pedons WYGLOO6 and WYGL007. Moderately deep, well-drained Dystric Cryochrepts (fine-loamy, mixed) developed in weathered residuum from the mafic igneous intrusives are included in the map unit. They support vegetation communities similar to the Dystric Cryochrepts (loamy-skeletal, mixed). A representative profile description together with selected physical and chemical laboratory data for these included soils are those provided for pedon WYGL012.

8. Histic Cryaquepts - Aeric Cryaquepts complex, 0–10% slopes

This complex consists of deep, poorly and somewhat poorly drained soils on nearly level to gently sloping toeslopes and valley bottoms along streams. They are developed in alluvium and water-reworked colluvium and glacial drift. The Histic Cryaquepts occur in the lowest slope positions and in depressional areas. The Aeric Cryaquepts are typically associated with slightly higher slope positions, farther removed from the active stream course. For both named components, permeability is moderate to rapid, surface runoff is very slow to medium, and erosion hazard is low. The soils of this map unit primarily support thick stands of willow and herbaceous, wet meadow vegetation.

Histic Cryaquepts (loamy-skeletal, mixed) make up about 50% of the map unit. Aeric Cryaquepts (loamy-skeletal, mixed) make up about 40% of the map unit. Included in the mapping are small areas of Humic Cryaquepts (loamy-skeletal, mixed), Aquic Cryumbrepts (loamy-skeletal, mixed), Typic Cryofluvents (loamy-skeletal, mixed), and Typic Cryorthents (loamy-skeletal, mixed). These inclusions make up about 10% of the total extent of the map unit in the survey area.

These soils are limited within the survey area. They are located in the drainages downstream from the outlet of West Glacier Lake and Lost Lake. Samples for the major components were not collected. The named components and inclusions were observed during field work. Pedon WYGL011 may be considered representative of some of the soils included in this unit.

9. Rubbleland, nearly level to moderately steep

These areas consist of deep, complex combinations of alluvium, colluvium, and glacial debris. They are primarily associated with drainages, either as inlets or outlets to lakes, and are often located at the base of steep colluvial slopes. Slopes range from 0–35% and are variable and complex in shape. Internal drainage of these areas is extremely variable and site-specific, ranging from ponded to excessively drained. The permeability of these areas is extremely rapid. Little or no surface runoff is experienced, although subsurface flow through this material was observed. This, coupled with the extreme stoniness of these areas, maintains a low erosion hazard. The vegetation of these areas is limited to small isolated accumulations of fine soil material and is typically herbaceous.

Rubbleland comprises approximately 90% of these areas. Included in the mapping are small areas of Dystric Cryochrepts (loamy-skeletal, mixed) and Typic Cryorthents (loamy-skeletal over fragmental, mixed). These inclusions make up about 10% of the total extent of the map unit within the survey area.

10. Rubbleland - Rock Outcrop complex, steep to extremely steep

These areas consist of colluvium and bedrock on steep backslope and shoulder positions of mountain sides. Both quartzite and mafic igneous intrusive rock types occur. Slopes range from 35–90% and are plane in shape. Internal drainage of these areas is primarily excessive. The permeability of these areas is extremely rapid. Little or no surface runoff is experienced, although subsurface flow through this material from associated perennial snow and ice accumulations was observed. The lack of surface flow, coupled with the extreme stoniness of these areas, maintain a low erosion hazard. The vegetation of these areas is limited to small isolated accumulations of fine soil material and is typically herbaceous. The lack of significant lichen development on the rock of these areas indicates the probable instability of these slopes and/or the high seasonal avalanche activity.

Rubbleland comprises approximately 55% of these areas. Rock Outcrop makes up about 40% of the unit. Included in the mapping are small areas of the named components on slopes less than 35% and greater than 90%, Dystric Cryochrepts (loamy-skeletal, mixed), and Typic Cryorthents (loamy-skeletal over fragmental, mixed). These inclusions make up about 5% of the total extent of the map unit within the survey area.

11. Permanent Snowfields and Icefields

These areas consist of permanent snowfields and/or icefields. Most of these areas are on the upper third of backslopes and on shoulders of mountain sides. Slopes are extremely variable but are predominantly greater than 60%. Small areas of Rubbleland and Rock Outcrop comprise less than 5% of the total mapped extent of this unit, with the remainder being permanent snowfields and/or icefields.

12. Typic Cryorthents - Rubbleland complex, 25–45% slopes

This complex consists of deep, well-drained soils and talus on steep and extremely steep portions of backslopes of mountain sides. The mapping unit has sparse open areas of herbaceous vegetation and talus.

Typic Cryorthents (loamy-skeletal, mixed) make up about 55% of the map unit. Rubbleland makes up about 40% of the unit. Included in the mapping are small areas of the named components on slopes less than 45% and greater than 75%, and Rock Outcrop. These inclusions make up about 5% of the total extent of the map unit within the survey area.

The Typic Cryorthents are deep, are well-drained, and have moderate to very rapid permeability. They are formed in colluvium and are typically associated with moderately steep and steep slopes on the backslopes of mountain sides occurring throughout the unit. Slopes are 45–55%, 10–50 m in length, and plane or slightly concave in shape. Surface runoff is rapid to very rapid and the erosion hazard is moderate to very severe depending on the extent of permanently established vegetation. The majority of roots are located in the upper 50 cm of the profile with lesser amounts of very fine roots extending to more than 90 cm. Most areas of these soils support sparse herbaceous vegetation.

In a representative profile of these Typic Cryorthents the surface layer is a dark brown, extremely gravelly, silt loam about 21 cm thick. The underlying layer is a brown to pale brown, extremely gravelly, sandy loam about 22 cm thick. The next layer is a brown to pale brown, extremely stony, coarse sandy loam to more than 92 cm.

Detailed profile descriptions and associated selected physical and chemical laboratory data for representative soils are those provided for pedons WYGL004 and WYGL008.

Rubbleland consists of rock talus on steep to extremely steep slopes on backslopes of mountain sides. Little or no fine earth material fills the interstices between the cobblestones, stones, and boulders composing the talus. These areas do not support vegetation. However, small, isolated areas having thin deposits of soil do support sparse herbaceous vegetation. Little or no surface runoff is experienced from these areas although snow meltwater is known to pass freely downslope through this material.

13. Dystric Cryochrepts - Lithic Cryumbrepts - Rock Outcrop complex, 15–45% slopes

This complex consists of moderately deep and shallow, well-drained soils and outcrops of quartzite and mafic igneous intrusive rock on gently sloping to moderately steep backslopes and footslopes of mountain sides and ridges. These areas serve as unconfined drainages for snow meltwater and runoff from high intensity storms. Free water is commonly found in the profiles of these soils, although their internal drainage is typically good. The soils of this mapping unit primarily support dense stands of willow and krummholz vegetation. Small areas of herbaceous vegetation occur throughout.

Dystric Cryochrepts (loamy-skeletal, mixed) make up about 40% of the map unit. Lithic Cryumbrepts (loamy-skeletal, mixed) make up about 30% of the unit. Rock Outcrop makes up about 20% of the map unit. Included in the mapping are small areas of the named components on slopes less than 5% and greater than 40%, Typic Cryumbrepts (loam-skeletal, mixed), and Rubbleland. These inclusions make up about 10% of the total extent of the map unit in the survey area.

The Dystric Cryochrepts are moderately deep, moderately well- and well- drained, and have medium to rapid permeability. They are formed in water- reworked colluvium and coarse glacial debris, and are typically associated with unconfined drainages and overflow areas on gently sloping to moderately steep slopes. Slopes are 5–25%, 10–25 m in length, and plane and slightly concave in shape. Surface runoff is limited due to a litter layer at the surface in most areas, and the erosion hazard is low. However, seasonal high flows during runoff of snowmelt and high intensity rain storms can result in high-volume, rapid surface flow. While the internal drainage of these soils is generally good, free water may be found in them from downslope subsurface flow. This water is apparently well-oxygenated, since indicators of restricted drainage do not develop. The majority of roots are located in the upper 30 cm of the profile with lesser amounts of very fine roots extending to about 100 cm. Most areas of these soils support dense stands of willow.

In a representative profile of the Dystric Cryochrepts the surface layer is a very dark gray to very dark grayish-brown, extremely stony peat or mucky peat about 12 cm thick. The subsoil is a yellowish-red to very pale brown, extremely stony, sandy loam about 34 cm thick over a brown to pale brown, extremely stony, sandy loam to about 100 cm. A description and associated physical and chemical laboratory data for a similar soil are those provided for pedon WYGL014. It should be noted that this soil contains fewer rock fragments in the upper portions of the profile than is typical.

The Lithic Cryumbrepts are shallow, moderately well- and well-drained, and have moderate to rapid permeability. As is the case for the Dystric Cryochrepts in this unit, free water from subsurface flow may be found in the profile. They are formed in water-reworked colluvium and coarse glacial debris and are generally closely

associated with structural benches on moderately steep and steep slopes. Fracturing in the quartzite bedrock is extensive and deep in most areas within the survey area. Consequently, these Lithic Cryumbrepts occur in close association with outcropping of the bedrock and are not disseminated throughout the unit. Slopes are 20–45%, about 10 m in length, and plane or slightly concave in shape. Surface runoff is medium to rapid, but the erosion hazard is low due to thick surface vegetation. The majority of roots are located in the upper 30 cm of the profile with lesser amounts of very fine roots extending to the bedrock contact at 50 cm or less. Most areas of these soils support herbaceous vegetation.

These soils are similar to the Dystric Cryochrepts described above but differ by being less than 50 cm to a hard bedrock contact and by having a thicker surface layer that contains high amounts of humic material. Samples of the soils were not collected but their presence and extent were observed during field work.

Outcrops of quartzite and mafic igneous intrusive bedrock are associated with gently sloping to moderately steep structural benches. Slopes are typically 5–40%, but may be greater or lesser for short slope lengths. Slope shape is variable and complex. The vegetation of these areas is limited to lichens and mosses.

W. Water

This unit consists of streams, lakes, and ponds that contain water throughout the year or for much of the year in most years. The minimum size of delineations is approximately 0.5 ha. The major delineations of this unit include East Glacier Lake, West Glacier Lake, and Lost Lake.

Appendix E.

Representative Pedon Descriptions for the Soils of the GLEES Wyoming Soil Survey Area: East Glacier Lake, West Glacier Lake, and Lost Lake Watersheds

R.W.E. Hopper and P.M. Walthall
Agronomy Department, Colorado State University
Fort Collins, Colorado

A soil survey was conducted of the East Glacier, West Glacier and Lost Lake watersheds in July-September 1986. Procedures appropriate for an Order 3 soil survey were followed. Fifteen locations were surveyed and a total of 166 samples were analyzed. The 15 series are listed below, along with the soil classification and number of samples analyzed.

Series	Classification	# of Samples Sites
WYGL001	Loamy-skeletal, mixed Typic Cryoboralf	7
WYGL002	Loamy-skeletal, mixed Typic Cryoboralf	9
WYGL003	Loamy-skeletal, mixed Dystric Cryochrept	4
WYGL004	Loamy-skeletal, mixed Typic Cryorthent	4
WYGL005	Loamy-skeletal, mixed Typic Cryorboralf	7
WYGL006	Loamy-skeletal, mixed Dystric Cryochrept	7
WYGL007	Loamy-skeletal, mixed Dystric Cryochrept	7
WYGL008	Loamy-skeletal, mixed Typic Cryorthent	4
WYGL009	Loamy-skeletal, mixed Typic Cryumbrept	4
WYGL010	Loamy-skeletal, mixed Typic Cryumbrept	5
WYGL011	Loamy-skeletal, mixed Humic Cryaquepts	4
WYGL012	Fine-loamy, Dystric Cryochrept	6
WYGL014	Coarse-loamy, mixed Dystric Cryochrept	3
WYGL015	Loamy-skeletal, mixed Dystric Cryochrept	6
WYGL016	Loamy-skeletal, mixed Typic Cryoboralf	7

For each series, representative descriptions of various horizons are provided in this Appendix. Identification of color (e.g., yellowish-brown, with the notation 10YR 5/4) is based on standard Munsell color notation. Soil descriptions were prepared by R.W.E. Hopper, P.M. Walthall, R. Aguilar, R. Knox, and E. Roswall of the Agronomy Department at Colorado State University.

SERIES: WYGL001

SOIL SURVEY # S86–56–001–001

LOCATION: Lat. 41° 22' 30" Long. 106° 15' 26"

CLASSIFICATION: Loamy-skeletal, mixed Typic Cryoboralf

PHYSIOGRAPHY: Moraine in glaciated uplands

GEOMORPHIC POSITION: on middle third of component; backslope sideslope

SLOPE: 12% plane, west facing

ELEVATION: 3286 m MSL

PRECIPITATION: Udic moisture regime

WATER TABLE DEPTH: None Observed

PERMEABILITY: Moderately rapid

DRAINAGE: Well drained

STONINESS: CLASS 2

EROSION OR DEPOSITION: Slight

FAMILY CONTROL SECTION: 11 to 61 cm

RUNOFF: Very rapid

PARENT MATERIAL: glacial till from mixed-igneous & metamorphic material

DIAGNOSTIC HORIZONS: 3 to 0 cm Ochric; 0 to 11 cm Ochric; 0 to 11 cm Albic; 11 to 31 cm Argillic

DESCRIBED BY: Hopper, Walthall, Aguilar SAMPLE DATE: 07/86

NOTES: pit is located on the southeast side of West Glacier Lake on the west flank of the rock-cored moraine separating West and East Glacier Lakes; spruce-fir forest vegetation. Descriptions are listed by soil horizons.

Oi. 3–2 cm; black (10YR 2/1) fibric material consisting of undecomposed and partially decomposed forest litter; very dark grayish-brown (10YR 3/2) dry; loose, nonsticky, nonplastic; common very fine, fine and medium roots throughout; abrupt smooth boundary. (Sampled with Oa in sample no. WYGL0011.)

Oa. 2–0 cm; black (10YR 2/1) sapric material consisting of well-decomposed forest litter; very dark grayish-brown (10YR 3/2) dry; moderate medium subangular blocky structure parting to moderate fine subangular blocky and fine granular; soft, very friable, nonsticky, nonplastic; many very fine and fine roots and common medium roots throughout; abrupt smooth boundary. (Sample no. WYGL0011.)

E. O–3 cm; yellowish-brown (10YR 5/4) loam; very pale brown (10YR 7/3) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine granular; soft, very friable, nonsticky, nonplastic; many very fine and fine roots and common medium roots throughout; clear smooth boundary. (Sample no. WYGL0012.)

2EB. 3–11 cm; yellowish-brown (10YR 5/4) very gravelly loam; very pale brown (10YR 7/3) dry; moderate fine platy structure parting to moderate fine and very fine granular; soft, very friable, nonsticky, nonplastic; many very fine and fine roots and common medium roots throughout; few discontinuous faint yellowish-brown (10YR 5/4) clay films on vertical and horizontal faces of peds and yellowish-brown (10YR 5/4) clay films on rock fragments; 50% pebbles; quartzite rock fragments with soft weathered masses of mafic intrusive rock; clear wavy boundary. (Sample no. WYGL0013.)

2Bt. 11–31 cm; brown to dark brown (7.5YR 4/4) extremely gravelly silty clay loam; light brown (7.5YR 6/4) dry; moderate fine subangular blocky structure parting to moderate very fine subangular blocky; soft, friable, slightly sticky, plastic; many very fine and fine roots throughout; common discontinuous distinct brown to dark brown (7.5YR 4/4) clay films on vertical and horizontal faces of peds and brown to dark brown (7.5YR 4/4) clay films on rock fragments; 70% pebbles; gradual wavy boundary. (Sample no. WYGL0014.)

2BC1. 31–66 cm; yellowish-brown (10YR 5/4) and brown to dark brown (7.5YR 4/4) very cobbly sandy loam; yellow (10YR 7/6) dry; approximately 10% of the horizon consists of lenses and unconsolidated masses of strong brown (7.5YR 5/6) very cobbly sandy clay loam; moderate medium subangular blocky structure parting to moderate fine subangular blocky; soft, friable, nonsticky, nonplastic; many very fine and fine roots throughout; common discontinuous distinct yellowish-brown (10YR 5/4) clay films on vertical and horizontal faces of peds and yellowish-brown (10YR 5/4) clay films on rock fragments; 35% cobbles; 20% pebbles; dominantly quartzite rock fragments; gradual wavy boundary. (Sample no. WYGL0015.)

2BC2. 66–100 cm; yellowish-brown (10YR 5/6) and strong brown (7.5YR 5/6) very cobbly sandy loam; yellow (10YR 8/6) and strong brown (7.5YR 5/6) dry; weak medium subangular blocky structure parting to weak very fine subangular blocky; soft, very friable, nonsticky, nonplastic; common very fine roots throughout; common discontinuous faint clay bridging between sand grains; common discontinuous distinct yellowish-brown (10YR 5/6) clay films on rock fragments; loose clean quartz coarse sand throughout horizon; 35% cobbles; 20% pebbles; dominantly quartzite rock fragments. (Sample no. WYGL0016.)

SERIES: WYGL002

SOIL SURVEY # S86–56–001–002

LOCATION: LAT. 41° 22' 35" Long. 106° 15' 10"

Base Map Location (Appendix F): X = 16.6, Y = 9.3.

CLASSIFICATION: Loamy-skeletal, mixed Typic Cryoboralf

PHYSIOGRAPHY: Hillside in glaciated uplands

GEOMORPHIC POSITION: on upper third of component; backslope

SLOPE: 20% convex, southwest facing

ELEVATION: 3298 m MSL

PRECIPITAITON: Udic moisture regime

WATER TABLE DEPTH: None observed

PERMEABILITY: Moderately rapid

DRAINAGE: Well drained

STONINESS: CLASS 4

EROSION OR DEPOSITION: Slight

FAMILY CONTROL SECTION: 16 to 47 cm

RUNOFF: Very rapid

PARENT MATERIAL: glacial till from dominantly quartzite material

DIAGNOSTIC HORIZONS: 3 to 0 cm Ochric; 0 to 16 cm Ochric; 0 to 25 cm Albic; 16 to 47 cm Argillic

DESCRIBED BY: Hopper, Aguilar SAMPLE DATE: 07/86

NOTES: pit is located on backslope of ridge to the east of East Glacier Lake; spruce-fir krummholz vegetation.

Oi. 3–2 cm; very dark gray (10YR 3/1) fibric material consisting of undecomposed and partially decomposed forest litter; dark grayish-brown (10YR 4/2) dry; loose, nonsticky, nonplastic; abrupt smooth boundary. (Sampled with Oa in sample no. WYGL0021.)

Oa. 2–0 cm; very dark gray (10YR 3/1) sapric material consisting of well- decomposed forest litter; dark grayish-brown (10YR 4/2) dry; moderate medium subangular blocky structure; soft, very friable, nonsticky; many very fine and fine roots and common medium roots throughout; abrupt smooth boundary. (Sample no. WYGL0021.)

E. 0–8 cm; brown (7.5YR 5/4) gravelly coarse sandy loam; light gray (10YR 7/2) dry; weak fine subangular blocky structure; soft, very friable, nonsticky, nonplastic; many very fine and fine roots and common medium roots throughout; many very fine tubular pores; 20% pebbles; dominantly quartzite rock fragments; abrupt wavy boundary. (Sample no. WYGl0022.)

EB. 8–16 cm; light brown (7.5YR 6/4) gravelly coarse sandy loam; very pale brown (10YR 7/3) dry; weak medium subangular blocky structure parting to weak fine and weak very fine subangular blocky; soft, friable, nonsticky, nonplastic; many very fine and fine roots and few medium roots throughout; many very fine tubular pores; common discontinuous prominent light gray (10YR 7/2) skeletons (sand or silt) on vertical and horizontal faces of peds; very few patchy distinct light brown (7.5YR 6/4) clay films on vertical and horizontal faces of peds; 20% pebbles; dominantly quartzite rock fragments; clear wavy boundary. (Sample no. WYGL0023.)

BEt. 16–25 cm; light yellowish-brown (10YR 6/4) very gravelly sandy loam; very pale brown (10YR 7/4) dry; weak medium subangular blocky structure parting to weak fine and weak very fine subangular blocky; soft, friable, slightly sticky, slightly plastic; many very fine and fine roots throughout and few medium roots throughout; many very fine tubular pores; common patchy prominent light gray (10YR 7/2) skeletons (sand or silt) on vertical and horizontal faces of peds; few patchy distinct light brown (7.5YR 6/4) clay films on vertical and horizontal faces of peds; 10% cobbles; 30% pebbles; dominantly quartzite rock fragments; abrupt wavy boundary. (Sample no. WYGL0024.)

Bt. 25–47 cm; brownish-yellow (10YR 6/6) and reddish-brown (5YR 4/4) very gravelly loam; light yellowish-brown (10YR 6/4) and reddish-yellow (7.5YR 6/6) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine subangular blocky; slightly hard, firm, nonsticky, nonplastic; many very fine and fine roots and few medium roots throughout; many very fine tubular pores; common discontinuous distinct brownish-yellow (10YR 6/6) clay films on vertical and horizontal faces of peds; 10% cobbles; 30% pebbles; dominantly quartzite rock fragments; clear wavy boundary. (Sample no. WYGL0025.)

BC1. 47–61 cm; yellowish-brown (10YR 5/6) and reddish-brown (5YR 4/4) very gravelly loam; very pale brown (10YR 7/4) and reddish-yellow (7.5YR 6/6) dry; weak medium subangular blocky structure parting to weak fine and weak very fine subangular blocky; slightly hard, firm, nonsticky, nonplastic; many very fine and fine roots throughout; many very fine tubular pores; few patchy distinct yellowish-brown (10YR 5/6) clay films on vertical and horizontal faces of peds; 10% cobbles; 30% pebbles; dominantly quartzite rock fragments; clear wavy boundary. (Sample no. WYGL0026.)

BC2. 61–73 cm; yellowish-brown (10YR 5/6) and reddish-brown (5YR 4/4) very gravelly loam; very pale brown (10YR 8/4) and reddish-yellow (7.5YR 6/6) dry; weak medium subangular blocky structure parting to weak fine and weak very fine subangular blocky; slightly hard, firm, nonsticky, nonplastic; many very fine and fine roots throughout; many very fine tubular pores; very few patchy distinct yellowish-brown (10YR 5/6) clay films on vertical and horizontal faces of peds; 10% cobbles; 30% pebbles; dominantly quartzite rock fragments; abrupt irregular boundary. (Sample no. WYGL0027.)

BC3. 73–101 cm; brownish-yellow (10YR 6/6) and strong brown (7.5YR 5/6) very cobbly loam; very pale brown (10YR 8/4) and reddish-yellow (7.5YR 6/6) dry; weak medium subangular blocky structure parting to weak very fine subangular blocky; slightly hard, friable, nonsticky, nonplastic; few very fine and fine roots throughout; common very fine interstitial and tubular pores; 30% cobbles; 20% pebbles; dominantly quartzite rock fragments; abrupt irregular boundary. (Sample no. WYGL0028.)

SERIES: WYGL003

SOIL SURVEY # S86–56–001–003

LOCATION: Lat. 41° 22' 36" Long. 106° 15' 7"

Base Map Location (Appendix F): X = 18.1, Y = 11.4.

CLASSIFICATION: Loamy-skeletal, mixed Dystric Cryochrept

PHYSIOGRAPHY: Upland slope in glaciated uplands

GEOMORPHIC POSITION: on middle third of component; shoulder of headslope

SLOPE: 10% convex, west facing

ELEVATION: 3304 m MSL

PRECIPITATION: Udic moisture regime

WATER TABLE DEPTH:

PERMEABILITY: Moderately rapid

DRAINAGE: Well drained

STONINESS: CLASS 4

EROSION OR DEPOSITION: Slight

FAMILY CONTROL SECTION: 25 to 59 cm

RUNOFF: Rapid

PARENT MATERIAL: residuum from quartzite material over solid rock from quartzite material (see notes)

DIAGNOSTIC HORIZONS: 0 to 12 cm Ochric 12 to 30 cm Cambic

DESCRIBED BY: Hopper, Aguilar SAMPLE DATE: 07/86

NOTES: pedon on alpine ridge east of East Glacier Lake; it is believed that the parent material for this soil is a combination of residuum and nivation debris with slight eolian influence.

A. 0–2 cm; very dark grayish-brown (10YR 3/2) extremely gravelly sandy loam; yellowish-brown (10YR 5/4) dry; weak medium subangular blocky structure parting to moderate very fine subangular blocky; soft, friable, nonsticky, nonplastic; many very fine and fine

roots throughout; 10% stones; 15% cobbles; 40% pebbles; abrupt smooth boundary. (Sample no. WYGL0031.)

2Bw. 2–30 cm; brown to dark brown (7.5YR 4/4) extremely gravelly coarse sandy loam; reddish-yellow (7.5YR 6/6) dry; weak medium subangular blocky structure parting to weak very fine granular; loose, very friable, slightly sticky, nonplastic; common very fine roots throughout; 5% stones; 20% cobbles; 60% pebbles; clear wavy boundary. (Sample no. WYGL0032.)

2BC. 30–47 cm; yellowish-brown (10YR 5/6) extremely stony fine sandy loam; very pale brown (10YR 7/4) dry; weak medium subangular blocky structure parting to weak very fine granular; soft, friable, slightly sticky, slightly plastic; common very fine roots throughout; 60% stones; 25% pebbles; clear irregular boundary. (Sample no. WYGL0033.)

3C. 47–59 cm; yellow (10YR 7/6) extremely stony fine sandy loam; very pale brown (10YR 8/4) dry; weak medium subangular blocky structure parting to weak very fine granular; soft, friable, slightly sticky, slightly plastic; few very fine roots throughout; 60% stones; 25% pebbles; abrupt irregular boundary. (Sample no. WYGL0034; Sample taken from interstices of the highly fractured quartzite bedrock).

R. 59 cm; slightly weathered to unweathered quartzite bedrock.

SERIES: WYGL004

SOIL SURVEY # S86–56–001–004

LOCATION: Lat. 41° 22' 46" Long. 106° 15' 17"

Base Map Location (Appendix F): X = 17.2, Y = 10.9.

CLASSIFICATION: Loamy-skeletal, mixed Typic Cryorthent

PHYSIOGRAPHY: Upland slope in glaciated uplands

GEOMORPHIC POSITION: on upper third of component; shoulder of headslope

SLOPE: 10% convex, south facing

ELEVATION: 3383 m MSL

PRECIPITATION: Udic moisture regime

WATER TABLE DEPTH: None observed

PERMEABILITY: Rapid

DRAINAGE: Well drained

STONINESS: CLASS 4

EROSION OR DEPOSITION: Moderate

FAMILY CONTROL SECTION: 25 to 100 cm

RUNOFF: Very rapid

PARENT MATERIAL: local colluvium from quartzite material

DIAGNOSTIC HORIZONS: 1 to 0 cm Ochric 0 to 3 cm Ochric

DESCRIBED BY: Hopper, Aguilar SAMPLE DATE: 07/86

NOTE: pit is located on the shoulder of the alpine ridge north of East Glacier Lake.

Oi. 1–0 cm; very dark gray (10YR 3/1) fibric material consisting of undecomposed and partially decomposed herbaceous litter; dark grayish-brown (10YR 4/2) dry; loose, nonsticky, nonplastic; many very fine and fine roots throughout; abrupt broken boundary. (This horizon not sampled because of its thin and discontinuous nature.)

A. O–3 cm; very dark grayish-brown (10YR 3/2) extremely gravelly loam; dark yellowish-brown (10YR 4/4) dry; weak medium subangular blocky structure parting to weak very fine granular; soft, friable, slightly sticky, plastic; many very fine and fine roots throughout; 10% cobbles; 60% pebbles; abrupt smooth boundary. (Sample no. WYGL0041.)

CA. 3–24 cm; dark yellowish-brown (10YR 3/4) extremely gravelly loam; light yellowish-brown (10YR 6/4) dry; weak medium subangular blocky structure parting to weak fine and weak very fine subangular blocky; soft, friable, slightly sticky, plastic; many very fine and fine roots throughout; few, patchy, faint, dark yellowish-brown (10YR 3/4) pressure faces on vertical and horizontal faces of peds; 5% stones; 50% cobbles; 30% gravel; clear irregular boundary. (Sample no. WYGL0042.)

Cl. 24–46 cm; dark yellowish-brown (10YR 4/4) extremely stony coarse sandy loam; light yellowish-brown (10YR 6/4) dry; weak fine and weak very fine granular; soft, friable, nonsticky, plastic; common very fine roots throughout; 70% stones; 10% cobbles; 5% pebbles; clear irregular boundary. (sample no. WYGL0043.)

C2. 46–64 cm; dark yellowish-brown (10YR 4/4) extremely stony coarse sandy loam; light yellowish-brown (10YR 6/4) dry; weak fine and weak very fine granular; soft, very friable, slightly sticky, slightly plastic; few very fine roots throughout; 70% stones; 10% cobbles; 5% pebbles; abrupt irregular boundary. (Sample no. WYGL0044.)
R. 64 cm; Slightly weathered and unweathered quartzite bedrock.

SERIES: WYGL005

SOIL SURVEY # S86–56–001–005

LOCATION: Lat. 41° 22' 39" Long. 106° 15' 8"
Base Map Location (Appendix F): X = 17.8, Y = 12.6.

CLASSIFICATION: Loamy-skeletal, mixed Typic Cryoboralf

PHYSIOGRAPHY: Hillside or mountain side in glaciated uplands

GEOMORPHIC POSITION: on middle third of component; backslope of headslope

MICRORELIEF:

SLOPE: 25% convex, west facing

ELEVATION: 3300 m MSL

PRECIPITATION: Udic moisture regime

WATER TABLE DEPTH: None observed

PERMEABILITY: Moderately rapid

DRAINAGE: Well drained

STONINESS: CLASS 2

EROSION OR DEPOSITION: Slight

FAMILY CONTROL SECTION: 17 to 67 cm

RUNOFF: Rapid

PARENT MATERIAL: glacial till from quartzite material

DIAGNOSTIC HORIZONS: 4 to 0 cm Ochric; 0 to 9 cm Ochric; 0 to 17 cm Albic; 17 to 67 cm Argillic

DESCRIBED BY: Hopper, Knox SAMPLE DATE: 07/86

NOTE: pit is located at midbackslope of ridge east of East Glacier Lake; spruce-fir forested vegetation.

Oi. 4–3 cm; very dark gray (10YR 3/1) fibric material consisting of undecomposed and partially decomposed forest litter; very dark grayish-brown (10YR 3/2) dry; loose, nonsticky, nonplastic; 5% quartzite cobbles; abrupt smooth boundary. (Sampled with Oa in sample no. WYGL0051.)

Oa. 3–0 cm; very dark gray (10YR 3/1) sapric material consisting of well- decomposed forest litter; very dark grayish-brown (10YR 3/2) dry; moderate medium subangular blocky structure; soft, very friable, nonsticky, nonplastic; many very fine and fine roots and common medium roots throughout; 5% cobbles; dominantly quartzite rock fragments; abrupt smooth boundary. (sample no. WYGL0051.)

E. O–9 cm; dark grayish-brown (10YR 4/2) gravelly loam; pale brown (10YR 6/3) dry; moderate medium subangular blocky structure parting to moderate fine granular; soft, friable, slightly sticky, plastic; many very fine and fine roots and few to common medium and coarse roots throughout; many very fine tubular pores; 5% cobbles; 15% pebbles; dominantly quartzite rock fragments; abrupt smooth boundary. (Sample no. WYGL0052.)

BE. 9–17 cm; yellowish-red (5YR 5/6) and pink (7.5YR 7/4) gravelly sandy loam; very pale brown (10YR 7/3) dry; moderate medium granular structure parting to moderate fine and moderate very fine granular; soft, friable, sticky, plastic; many very fine and fine roots and common medium roots throughout; many very fine tubular pores; 5% cobbles; 15% pebbles; predominantly quartzite rock fragments; clear wavy boundary. (Sample no. WYGL0053.)

Bt. 17–43 cm; yellowish-red (5YR 5/6) very gravelly loam; pink (7.5YR 8/4) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine subangular blocky; soft, friable, sticky, plastic; many very fine and fine roots and few medium roots throughout; common very fine tubular pores; 10% cobbles; 30% pebbles; dominantly quartzite rock fragments; approximately 5% of the rock fragments are mafic intrusives; clear wavy boundary. (Sample no. WYGL0054.)

BC1. 43–64 cm; brown (7.5YR 5/4) very cobbly loam; pink (7.5YR 7/4) dry; weak very fine subangular blocky structure; soft, friable, sticky, plastic; common very fine and fine roots throughout and common very fine roots matted around stones; few very fine tubular pores; 35% cobbles; 20% pebbles; dominantly quartzite rock fragments; approximately 5% of the rock fragments are mafic intrusives; abrupt wavy boundary. (Sample no. WYGL0055.)

BC2. 64–105 cm; brown (7.5YR 5/4) extremely gravelly loam; pink (7.5YR 7/4) dry; weak fine subangular blocky structure parting to weak very fine subangular blocky; soft, friable, slightly sticky, plastic; few very fine tubular pores; 55% pebbles; 15% cobbles; dominantly quartzite rock fragments; approximately 5% of the rock fragments are mafic intrusives; abrupt wavy boundary. (Sample no. WYGL0056.)

SERIES: WYGL006

SOIL SURVEY # S86–56–001–006

LOCATION: Lat. 41° 22' 50" Long. 106° 15' 3"

Base Map Location (Appendix F): X = 14.8, Y = 15.2.

CLASSIFICATION: Loamy-skeletal, mixed Dystric Cryochrept

PHYSIOGRAPHY: Mountain side in glaciated uplands

GEOMORPHIC POSITION: on lower third of component; backslope of headslope

SLOPE: 35% convex, south facing

ELEVATION: 3350 m MSL

PRECIPITATION: Udic moisture regime

WATER TABLE DEPTH: None observed

PERMEABILITY: Rapid

DRAINAGE: Well drained

STONINESS: CLASS 4

EROSION OR DEPOSITION: Slight

FAMILY CONTROL SECTION: 25 to 100 cm

RUNOFF: Rapid

PARENT MATERIAL: local colluvium from quartzite material

DIAGNOSTIC HORIZONS: 0 to 13 cm Ochric 13 to 23 cm Cambic

DESCRIBED BY: Hopper, Knox SAMPLE DATE: 07/86

NOTES: pit is located northeast of East Glacier Lake, north of WYGL005 past meadow on rock outcrop.

A. 0–5 cm; very dark grayish-brown (10YR 3/2) extremely gravelly silt loam; dark grayish-brown (10YR 4/2) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine granular; soft, friable, slightly sticky, plastic; many very fine and fine roots and common medium and coarse roots throughout; many very fine and fine roots matted around cobblestones and stones; common very fine tubular pores; 20% stones; 25% cobbles; 30% pebbles; abrupt smooth boundary. (Sample no. WYGL0061.)

E. 5–9 cm; brown to dark brown (10YR 4/3) extremely gravelly sandy loam; pale brown (10YR 6/3) dry; weak medium subangular blocky structure parting to moderate fine granular and moderate very fine granular; soft, very friable, slightly sticky, slightly plastic; many very fine and fine roots and common medium and course roots throughout; many very fine roots matted around cobblestones and stones; many very fine interstitial and tubular pores; 20% stones; 25% cobbles; 30% pebbles; abrupt smooth boundary. (Sample no. WYGL0062.)

BE. 9–13 cm; brown to dark brown (10YR 4/3) extremely gravelly sandy loam; pale brown (10YR 6/3) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine granular; soft, friable, slightly sticky, slightly plastic; many very fine and fine roots and common medium and coarse roots throughout; many very fine and fine roots matted around cobblestones and stones; many very fine interstitial and tubular pores; 20% stones; 25% cobbles; 30% pebbles; clear wavy boundary. (Sample no. WYGL0063.)

Bw. 13–23 cm; brown to dark brown (7.5YR 4/2) extremely gravelly loam; light yellowish brown (10YR 6/4) dry; moderate medium subangular blocky structure parting to moderate fine platy parting to moderate very fine granular; soft, friable, sticky, plastic; many very fine and fine roots and few medium roots throughout; many very fine and fine roots matted around cobblestones and stones; many very fine tubular pores; 20% stones; 25% cobbles; 30% pebbles; clear wavy boundary. (Sample no. WYGL0064.)

BC. 23–41 cm; light yellowish-brown (10YR 6/4) extremely gravelly sandy loam; white (10YR 8/2) dry; weak medium subangular blocky structure parting to weak fine and weak very fine granular; soft, friable, slightly sticky, slightly plastic; common very fine and fine roots throughout and matted around stones; common very fine tubular pores; 20% stones; 25% cobbles; 30% pebbles; clear irregular boundary. (Sample no. WYGL0065.)

Cl. 41–74 cm; light yellowish-brown (10YR 6/4) extremely stony sandy loam; white (10YR 8/2) dry; single grain; soft, friable, slightly sticky, slightly plastic; few very fine roots throughout and matted around stones; few very fine tubular pores; 75% stones; 10% pebbles; diffuse irregular boundary. (Sample no. WYGL0066.)

C2. 74–101 cm; light yellowish-brown (10YR 6/4) extremely stony sandy loam; white (10YR 8/2) dry; single grain; soft, friable, slightly sticky, slightly plastic; few very fine roots throughout; few very fine tubular pores; 75% stones; 10 pebbles. (Sample no. WYGL0067.)

SERIES: WYGL007

SOIL SURVEY # S86–56–001–007

LOCATION: Lat. 41° 22' 53" Long. 106° 15' 26"

Base Map Location (Appendix F): X = 12.6, Y = 13.8.

CLASSIFICATION: Loamy-skeletal, mixed Dystric Cryochrept

PHYSIOGRAPHY: Mountain side in glaciated uplands

GEOMORPHIC POSITION: on upper third of component; backslope of sideslope

SLOPE: 35% convex, south facing

ELEVATION: 3365 m MSL

PRECIPITATION: Udic moisture regime

WATER TABLE DEPTH: None observed

PERMEABILITY: Moderately rapid

DRAINAGE: Well drained

STONINESS: CLASS 2

EROSION OR DEPOSITION: Slight

FAMILY CONTROL SECTION: 25 to 100 cm

RUNOFF: Rapid

PARENT MATERIAL: local colluvium from quartzite material

DIAGNOSTIC HORIZONS: 6 to 0 cm Ochric; 0 to 26 cm Ochric; 0 to 10 cm Albic; 26 to 55 cm Cambic

DESCRIBED BY: Hopper, Knox SAMPLE DATE: 07/86

NOTES: pit is located in large island of vegetation directly north of East Glacier Lake on the backslope of the main ridge. Two vegetation types are associated with this area and soils were sampled in each: subalpine fir krummholz WYGL007 and open alpine, like WYGL008.

Oi. 6–4 cm; black (7.5YR 2/0) fibric material consisting of undecomposed and partially decomposed forest litter; very dark gray (10YR 3/1) dry; loose, nonsticky,

nonplastic; abrupt smooth boundary. (Sampled with Oa in sample no. WYGL0071.)

Oa. 4–0 cm; black (7.5YR 2/0) sapric material consisting of well-decomposed forest litter; very dark gray (10YR 3/1) dry; moderate medium subangular blocky structure; soft, very friable, nonsticky, nonplastic; many very fine and fine roots throughout; abrupt smooth boundary. (Sample no. WYGL0071.)

E. O–10 cm; brown to dark brown (10YR 4/3) silt loam; light yellowish-brown (10YR 6/4) dry; moderate medium subangular blocky structure parting to moderate fine and very fine granular; soft, very friable, slightly sticky, slightly plastic; many very fine and fine roots throughout and matted around stones; many very fine tubular pores; 10% pebbles approximately 5% of the rock fragments are mafic intrusives; abrupt wavy boundary. (Sample no. WYGL0072.)

BE. 10–26 cm; brown to dark brown (7.5YR 4/2) silt loam; light yellowish- brown (10YR 6/4) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine granular; soft, friable, slightly sticky, slightly plastic; many very fine and fine root and common medium and coarse roots throughout; many very fine tubular pores; 10% pebbles; approximately 5% of the rock fragments are mafic intrusives; clear wavy boundary. (Sample no. WYGL0073.)

Bw. 26–55 cm; brown to dark brown (7.5YR 4/4) very gravelly silt loam; light yellowish-brown (10YR 6/4) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine granular; soft, friable, slightly sticky, slightly plastic; many very fine and fine roots and common medium roots throughout; common very fine tubular pores; 10% stones; 25% pebbles; dominantly quartzite rock fragments; approximately 5% of the rock fragments are mafic intrusives; clear wavy boundary. (Sample no. WYGL0074.)

BC1. 55–85 cm; dark yellowish-brown (10YR 4/4) very gravelly fine sandy loam; light yellowish-brown (10YR 6/4) dry; moderate medium subangular blocky structure parting to moderate fine granular and moderate very fine granular; soft, friable, slightly sticky, slightly plastic; common very fine and fine roots and few medium roots throughout; few very fine tubular pores; 5% stone; 5% cobbles; 30% pebbles; dominantly quartzite rock fragments; approximately 5% mafic intrusives; abrupt wavy boundary. (Sample no. WYGL0075.)

BC2. 85–106 cm; dark yellowish-brown (10YR 4/4) extremely stony sandy loam; light yellowish-brown (10YR 6/4) dry; weak medium subangular blocky structure parting to weak fine and weak very fine granular; soft, friable, slightly sticky, slightly plastic; few very fine and fine roots throughout; few very fine tubular pores; 40% stones; 20% cobbles; 20% pebbles; dominantly quartzite rock fragments; about 5% of the rock fragments are mafic intrusives; abrupt irregular boundary. (Sample no. WYGL0076.)

R. 106 cm; Slightly weathered and unweathered quartzite bedrock.

SERIES: WYGL008

SOIL SURVEY # S86–56–001–008

LOCATION: Lat. 41° 22' 53" Long. 106° 15' 24"

Base Map Location (Appendix F): X = 12.7, Y = 13.9.

CLASSIFICATION: Loamy-skeletal, mixed Typic Cryorthent

PHYSIOGRAPHY: Mountain side in glaciated uplands

GEOMORPHIC POSITION: on upper third of component; backslope of sideslope

SLOPE: 5% convex, south facing

ELEVATION: 3365 m MSL

PRECIPITATION: Udic moisture regime

WATER TABLE DEPTH: None observed

PERMEABILITY: Rapid

DRAINAGE: Well drained

STONINESS: CLASS 5

EROSION OR DEPOSITION: Moderate

FAMILY CONTROL SECTION: 25 to 100 cm

RUNOFF: Very rapid

PARENT MATERIAL: local colluvium from quartzite material

DESCRIBED BY: Hopper, Knox SAMPLE DATE: 07/86

NOTES: pit located in large island of vegetation directly north of East Glacier Lake. Two vegetation types in this area and soils associated with each type were sampled: subalpine fir krummholz (WYGL007) and open alpine, like (WYGL008). Digging curtailed by amount and size of rocks at 92 cm. However, based on field observations it is felt that this soil is greater than 100 cm deep.

A. 0–21 cm; brown to dark brown (7.5YR 4/2) extremely gravelly silt loam; brown (10YR 5/3) dry; weak medium subangular blocky structure parting to weak fine and weak very fine subangular blocky; soft, friable, slightly sticky, slightly plastic; many very fine and fine roots and few medium roots throughout; many very fine roots matted around coarse pebbles, cobblestones and stones; common very fine tubular pores; 40% pebbles; 20% cobbles; 5% stones; clear wavy boundary. (Sample no. WYGL0081.)

AC. 21–51 cm; dark brown (10YR 3/3) extremely gravelly loam; brown (10YR 5/3) dry; weak medium subangular blocky structure parting to weak fine and weak very fine granular; soft, friable, slightly sticky,

plastic; many very fine and fine roots throughout and matted around stones; common very fine tubular pores; 40% pebbles; 20% cobbles; 5% stones; clear wavy boundary. (Sample no. WYGL0082.)

C1. 51–73 cm; brown to dark brown (10YR 4/3) extremely gravelly sandy loam; pale brown (10YR 6/3) dry; weak medium subangular blocky structure parting to weak fine and weak very fine granular; soft, friable, slightly sticky, slightly plastic; common very fine roots throughout and matted around stones; few very fine tubular pores; 40% pebbles; 20% cobbles; 5% stones; abrupt irregular boundary. (Sample no. WYGL0083.)

2C2. 73–92 cm; dark yellowish-brown (10YR 4/4) extremely stony coarse sandy loam; pale brown (10YR 6/3) dry; weak medium subangular blocky structure parting to weak fine and weak very fine granular; soft, friable, nonsticky, nonplastic; few very fine roots throughout and matted around stones; 65% stones; 20% pebbles. (Sample no. WYGL0084.)

SERIES: WYGL009

SOIL SURVEY # S86–56–001–009

LOCATION: Lat. 41° 22' 50" Long. 106° 15' 13"

Base Map Location (Appendix F): X = 15.2, Y = 13.2.

CLASSIFICATION: Loamy-skeletal, mixed Typic Cryumbrept

PHYSIOGRAPHY: Mountain side in glaciated uplands

GEOMORPHIC POSITION: on middle third of component; backslope of sideslope

SLOPE: 12% plane, south facing

ELEVATION: 3325 m MSL

PRECIPITATION: Udic moisture regime

WATER TABLE DEPTH: None observed

PERMEABILITY: Moderately rapid

DRAINAGE: Well drained

STONINESS: CLASS 1

EROSION OR DEPOSITION: Slight

FAMILY CONTROL SECTION: 25 to 100 cm

RUNOFF: Moderate

PARENT MATERIAL: local colluvium and alluvium derived primarily from quartzite material

DIAGNOSTIC HORIZONS: 0 to 45 cm Umbric 8 to 45 cm Cambic

DESCRIBED BY: Hopper, Knox SAMPLE DATE: 07/86

NOTES: pit is located in a grass meadow at the base of a talus slope in the upper third of the backslope north of East Glacier Lake.

A. 0–8 cm; dark brown (7.5YR 3/2) silt loam; brown (10YR 5/3) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine subangular blocky; soft, friable, slightly sticky, slightly plastic; many very fine and fine roots throughout; many very fine tubular pores; abrupt smooth boundary. (Sample no. WYGL0091.)

Bw. 8–45 cm; dark brown (10YR 3/3) silt loam; brown (10YR 5/3) dry; moderate coarse subangular blocky structure parting to moderate fine and moderate very fine platy; soft, friable, sticky, plastic; many very fine roots throughout; many very fine tubular pores; clear wavy boundary. (Sample no. WYGL0092.)

BC. 45–84 cm; brown to dark brown (10YR 4/3) and yellowish-brown (10YR 5/6) very stony loam; pale brown (10YR 6/3) and very pale brown (10YR 7/3) dry; lenses of yellowish-brown (10YR 5/6) coarse sandy loam and coarse loamy sand; moderate coarse subangular blocky structure parting to moderate fine and moderate very fine platy; soft, friable, sticky, plastic; few very fine roots throughout; common very fine tubular pores; 45% stones; 10% pebbles; abrupt irregular boundary. (Sample no. WYGL0093; coarser material occurring as lenses sampled separately as WYGL0095.)

2C. 84–110 cm; dark yellowish-brown (10YR 4/4) extremely stony silt loam; very pale brown (10YR 8/3) dry; common medium distinct yellowish-red (5YR 4/6) mottles; weak medium subangular blocky structure parting to weak fine granular parting to weak very fine granular; soft, friable, sticky, plastic; 55% stones; 10% cobbles; 15% pebbles. (Sample no. WYGL0094.)

SERIES: WYGL010

SOIL SURVEY # S86–56–001–010

LOCATION: Lat. 41° 22' 41" Long. 106° 15' 13"

Base Map Location (Appendix F): X = 15.6, Y = 10.3.

CLASSIFICATION: Loamy-skeletal, mixed Typic Cryumbrept

PHYSIOGRAPHY: Fan in glaciated uplands

GEOMORPHIC POSITION: on lower third of component; footslope of headslope

SLOPE: 6% plane, west facing

ELEVATION: 3261 m MSL

PRECIPITATION: Udic moisture regime

WATER TABLE DEPTH: None observed

PERMEABILITY: Moderately rapid

DRAINAGE: Moderately well drained

STONINESS: CLASS 1

EROSION OR DEPOSITION: Slight

FAMILY CONTROL SECTION: 25 to 100 cm

RUNOFF: Moderate

PARENT MATERIAL: local colluvium and alluvium derived from quartzite material

DIAGNOSTIC HORIZONS: 0 to 30 cm Umbric 9 to 30 cm Cambic

DESCRIBED BY: Hopper, Knox SAMPLE DATE: 07/86

NOTES: pit is located in meadow northeast of East Glacier Lake and is associated with one of the University of Wyoming lysimeter installations.

A. O–9 cm; dark brown (10YR 3/3) silt loam; brown to dark brown (10YR 4/3) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine granular; soft, friable, slightly sticky, slightly plastic; many very fine and fine roots and few to common medium and coarse roots throughout; common very fine tubular pores; clear smooth boundary. (Sample no. WYGL0101.)

Bw. 9–30 cm; dark brown (10YR 3/3) silt loam; yellowish-brown (10YR 5/4) dry; many fine distinct dark yellowish-brown (10YR 4/6) mottles; moderate coarse subangular blocky structure parting to moderate fine platy parting to moderate fine granular; soft, friable, slightly sticky, plastic; many very fine and fine roots throughout; common very fine tubular pores; many discontinuous prominent dark brown (10YR 3/3) pressure faces on bottoms of plates; abrupt wavy boundary. (Sample no. WYGL0102.)

BC. 30–59 cm; brown to dark brown (7.5YR 4/4) very stony silt loam; light yellowish-brown (10YR 6/4) dry; many coarse distinct yellowish-red (5YR 4/8) mottles; moderate coarse subangular blocky structure parting to weak fine platy parting to moderate fine granular; soft, friable, sticky, plastic; few very fine and fine roots throughout; few very fine tubular pores; common discontinuous prominent brown to dark brown (7.5YR 4/4) pressure faces on bottoms of plates; 25% stones; 10% cobbles; 5% pebbles; abrupt wavy boundary. (Sample no. WYGL0103.)

2C1. 59–91 cm; yellowish-brown (10YR 5/6) extremely cobbly sandy loam; very pale brown (10YR 8/4) dry; many medium prominent yellowish-red (5YR 4/8) and common coarse prominent yellowish-red (5YR 4/8) mottles; massive; soft, very friable, nonsticky, nonplastic; 25% stones; 40% cobbles; 5% pebbles; clear irregular boundary. (Sample no. WYGL0104.)

2C2. 91–108 cm; very pale brown (10YR 7/4) extremely cobbly sandy loam; very pale brown (10YR 8/3) dry; many coarse prominent strong brown (7.5YR 5/8) mottles massive; loose, very friable, nonsticky, nonplastic; 20% stones; 40% cobbles; 10% pebbles. (Sample no. WYGL0105.)

SERIES: WYGL011

SOIL SURVEY # S86–56–001–011

LOCATION: Lat. 41° 22' 38" Long. 106° 15' 11"

Base Map Location (Appendix F): X = 15.2, Y = 9.5.

CLASSIFICATION: Loamy-skeletal, mixed Humic Cryaquepts

PHYSIOGRAPHY: Mountain side in glaciated uplands

GEOMORPHIC POSITION: on lower third of component; toeslope of headslope

SLOPE: 8% concave, southwest facing

ELEVATION: 3246 m MSL

PRECIPITATION: Aquic moisture regime

WATER TABLE DEPTH: 79 cm - Apparent

PERMEABILITY: Moderate

DRAINAGE: Poorly drained

STONINESS: CLASS 1

EROSION OR DEPOSITION: Slight

FAMILY CONTROL SECTION: 25 to 100 cm

RUNOFF: Slow

PARENT MATERIAL: glacial till from quartzite material over local colluvium

and alluvium derived from quartzite material

DIAGNOSTIC HORIZONS: 0 to 45 cm Umbric

DESCRIBED BY: Hopper, Knox SAMPLE DATE: 07/86

NOTES: pit is located east of East Glacier Lake in thick stand of willow.

A1. 0–11 cm; very dark grayish-brown (10YR 3/2) silt loam; brown (10YR 5/3) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine granular; soft, friable, slightly sticky, plastic; many very fine and fine roots and common medium roots throughout; clear smooth boundary. (Sample no. WYGL0111.)

2A2. 11–45 cm; very dark grayish-brown (10YR 3/2) and streaks of very dark gray (10YR 3/1) silt loam; brown (10YR 5/3) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine granular; soft, friable, slightly sticky, plastic; many very fine and fine roots throughout; abrupt wavy boundary. (Sample no. WYGL0112.)

2AC. 45–58 cm; brown to dark brown (10YR 4/3) with bands and streaks of very dark grayish-brown (10YR 3/2) silt loam; light yellowish-brown (10YR 6/4) and grayish-brown (10YR 5/2) dry; many fine prominent very dark gray (10YR 3/1) mottles; moderate medium subangular blocky structure parting to moderate fine platy parting to moderate very fine granular; soft, fri-

able, slightly sticky, plastic; common very fine and fine roots throughout; common very fine and fine tubular pores; abrupt wavy boundary. (Sample no. WYGL0113.)

3C. 58–95 cm; brown to dark brown (7.5YR 4/4) extremely stony silt loam; very pale brown (10YR 7/3) dry; weak medium subangular blocky structure parting to weak fine and weak very fine granular; soft, friable, sticky, plastic; few very fine roots throughout; few very fine tubular pores; 60% stones; 10% cobbles; 10% pebbles. Watertable encountered at 79 cm within horizon. (Sample no. WYGL0114.)

SERIES: WYGL012

SOIL SURVEY # S86–56–001–012

LOCATION: Lat. 41° 22' 53" Long. 106° 15' 6"

Base Map Location (Appendix F): X = 16.8, Y = 13.8.

CLASSIFICATION: Fine-loamy, mixed Dystric Cryochrept

PHYSIOGRAPHY: Mountain side in glaciated uplands

GEOMORPHIC POSITION: on upper third of component; backslope of headslope

SLOPE: 25% convex, west facing

ELEVATION: 3325 m MSL

PRECIPITATION: Udic moisture regime

WATER TABLE DEPTH: None observed

PERMEABILITY: Moderate

DRAINAGE: Well drained

STONINESS: Class 1

EROSION OR DEPOSITION: Slight

FAMILY CONTROL SECTION: 25 to 55 cm

RUNOFF: Rapid

PARENT MATERIAL: residuum from mafic igneous intrusive rocks

DIAGNOSTIC HORIZONS: 5 to 0 cm Ochric 0 to 19 cm Cambic

DESCRIBED BY: Hopper SAMPLE DATE: 07/86

NOTES: pit is located northeast of East Glacier Lake on upper third of the backslope of the main ridge in a dense stand of spruce-fir krummholz vegetation; the soil appears to have formed in residuum of mafic intrusives; some colluvial influence is probable; the rock fragments in this soil are composed primarily of mafic intrusives.

Oi. 5–4 cm; very dark gray (5YR 3/1) fibric material consisting of undecomposed and partially decomposed forest litter; very dark grayish-brown (10YR 3/2) dry; loose, nonsticky, nonplastic; abrupt broken boundary. (Sampled with Oa in Sample no. WYGL0121.)

Oa. 4-O cm; very dark gray (5YR 3/1) sapric material consisting of well- decomposed forest litter; very dark grayish-brown (10YR 3/2) dry; weak medium subangular blocky structure; soft, very friable, nonsticky, nonplastic; common very fine and fine roots throughout and common very fine roots matted around stones; abrupt smooth boundary. (Sample no. WYGL0121.)

Bw. O–19 cm; dark brown (10YR 3/3) gravelly loam; brown to dark brown (10YR 4/3) dry; moderate medium subangular blocky structure parting to moderate fine granular; soft, friable, sticky, plastic; common very fine, fine, medium, and coarse roots throughout and common very fine roots matted around coarse pebbles and cobblestones; few very fine tubular pores; few patchy faint dark brown (10YR 3/3) pressure faces on vertical and horizontal faces of peds; 25% pebbles; 5% cobbles; clear wavy boundary. (Sample no. WYGL0122.)

BC. 19–33 cm; reddish-brown (2.5YR 4/4) and dark brown (10YR 3/3) loam; brown (10YR 5/3) and brown (7.5YR 5/4) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine granular; slightly hard, firm, sticky, plastic; common very fine, fine, medium, and coarse roots throughout and common very fine and fine roots matted around coarse pebbles and cobblestones; common very fine tubular pores; 10% pebbles; less than 5% cobbles; clear wavy boundary. (Sample no. WYGL0123.)

C. 33–55 cm; dark greenish-gray (5GY 4/1), dark brown (10YR 3/3), and reddish- brown (2.5YR 4/4) very gravelly clay loam; yellowish-brown (10YR 5/4), dark grayish-brown (2.5Y 4/2), and reddish-brown (2.5YR 4/4) dry; weak medium subangular blocky structure; slightly hard, firm, sticky, platic; few to common very fine and fine roots throughout and common very fine roots matted around coarse pebbles; few very fine tubular pores; 40% pebbles; abrupt wavy boundary (Sample no. WYGL0124.)

Cr. 55–72 cm; red (10R 4/6) and dark brown (10YR 3/3) clay; brown to dark brown (7.5YR 4/4) and weak red (10R 4/4) dry; hard, very firm, sticky, plastic; few very fine roots throughout. (Sample no. WYGL0125.)

SERIES: WYGL014

SOIL SURVEY # S86–56–001–014

LOCATION: Lat. 41° 22' 46" Long. 106° 15' 38"

Base Map Location (Appendix F): X = 12.8, Y = 10.7.

CLASSIFICATION: Coarse-loamy, mixed Dystric Cryochrept

PHYSIOGRAPHY: Mountain side in glaciated uplands

GEOMORPHIC POSITION: on upper third of component; backslope of sideslope

SLOPE: 6% convex

ELEVATION: 3319 m MSL

PRECIPITATION: Udic moisture regime

WATER TABLE DEPTH: 34 cm - Seasonal

PERMEABILITY: Moderately rapid

DRAINAGE: Well drained

STONINESS: Class 1

EROSION OR DEPOSITION: Slight

FAMILY CONTROL SECTION: 25 to 74 cm

RUNOFF: Rapid

PARENT MATERIAL: local colluvium from quartzite material

DIAGNOSTIC HORIZONS: 5 to 0 cm Ochric 0 to 32 cm Cambic

DESCRIBED BY: Hopper SAMPLE DATE: 08/86

NOTES: pit is located on backslope of ridge north of West Glacier Lake on the east side of the waterfall near the bottom of a snowfield on a bedrock bench; no evidence of restricted drainage; observed water table from subsurface flow of water due to snowmelt.

Oa. 5–0 cm; black (10YR 2/1) sapric material consisting of well-decomposed herbaceous litter; dark grayish-brown (10YR 4/2) dry; moderate fine granular structure; soft, friable, slightly sticky, slightly plastic; many very fine and fine roots throughout; abrupt smooth boundary. (Sample no. WYGL0141.)

Bw. O–32 cm; dark yellowish-brown (10YR 4/4) silt loam; light yellowish- brown (10YR 6/4) dry; weak medium subangular blocky structure parting to weak fine and weak very fine subangular blocky; soft, friable, slightly sticky, slightly plastic; many very fine and fine roots throughout; clear wavy boundary. (Sample no. WYGL0142.)

BC. 32–74 cm; dark yellowish-brown (10YR 4/4) silt loam; light yellowish- brown (10YR 6/4) dry; soft, friable, slightly sticky, slightly plastic; common very fine roots throughout; 40% cobbles; 15% pebbles; dominantly quartzite rock fragments; abrupt wavy boundary. (Sample no. WYGL0143.)

R. 74 cm; slightly weathered and unweathered quartzite bedrock.

SERIES: WYGL015

SOIL SURVEY # S86–56–001–015

LOCATION: Lat. 41° 22' 43" Long. 106° 15' 21"

CLASSIFICATION: Loamy-skeletal, mixed Dystric Cryochrept

PHYSIOGRAPHY: Moraine in glaciated uplands

GEOMORPHIC POSITION: on lower third of component footslope of sideslope

SLOPE: 6% plane, northeast facing

ELEVATION: 3292 m MSL

PRECIPITATION: Udic moisture regime

WATER TABLE DEPTH: None observed

PERMEABILITY: Moderately rapid

DRAINAGE: Well drained

STONINESS: CLASS 4

EROSION OR DEPOSITION: Moderate

FAMILY CONTROL SECTION: 25 to 100 cm

RUNOFF: Rapid

PARENT MATERIAL: local colluvium from quartzite material over glacial

till from quartzite material

DIAGNOSTIC HORIZONS: 0 to 7 cm Ochric 7 to 33 cm Cambic

DESCRIBED BY: Hopper, Roswall SAMPLE DATE: 09/86

NOTES: pit is located north-northeast of precipitation gage on rock-cored moraine between East and West Glacier Lakes on a bedrock-controlled bench; site is associated with the University of Wyoming lysimeter installations.

A. 0–7 cm; very dark gray (10YR 3/1) extremely cobbly loam; very dark grayish-brown (10YR 3/2) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine granular; soft, friable, slightly sticky, slightly plastic; many very fine and fine roots and common medium roots throughout and many very fine roots matted around coarse pebbles, cobblestones, and stones; common very fine tubular pores; 15% pebbles; 55% cobbles; 5% stones; abrupt broken boundary. (Sample no. WYGL0151.)

2BA. 7–15 cm; brown to dark brown (7.5YR 4/2) extremely cobbly loam; very dark grayish-brown (10YR 3/2) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine granular; soft, friable, slightly sticky, slightly plastic; many very fine and fine roots and common medium roots throughout and many very fine and fine roots matted around coarse pebbles, cobblestones and stones; common very fine tubular pores; common discontinuous distinct dark brown (7.5YR 3/2) clay films in root channels and/or pores; 15% pebbles; 55% cobbles; 5% stones; dominantly quartzite rock fragments; approximately 5% of the rock fragments are mafic intrusives; clear wavy boundary. (Sample no. WYGL0152.)

2Bw. 15–33 cm; brown to dark brown (7.5YR 4/2) extremely cobbly loam; very pale brown (10YR 7/4) dry; moderate medium subangular blocky structure parting to moderate fine platy parting to moderate very fine granular; soft, friable, slightly sticky, slightly plastic; many very fine and fine roots and few medium roots throughout and many very fine and fine roots matted

around coarse pebbles, cobblestones, and stones; common very fine tubular pores; few discontinuous distinct dark brown (7.5YR 3/2) clay films on faces of peds; 25% pebbles; 40% cobbles; 10% stones; dominantly quartzite rock fragments; approximately 5% of the rock fragments are mafic intrusives; clear wavy boundary. (Sample no. WYGL0153.)

2BC. 33–55 cm; yellowish-brown (10YR 5/4) and brown to dark brown (7.5YR 4/4) extremely cobbly loam; very pale brown (10YR 7/4) dry; moderate medium subangular blocky structure parting to moderate fine platy parting to moderate very fine granular; soft, friable, slightly sticky, slightly plastic; few to common very fine and fine roots throughout and matted around coarse pebbles, cobblestones and stones; common very fine tubular pores; common discontinuous faint yellowish-brown (10YR 5/4) pressure faces on horizontal faces of peds; common continuous prominent strong brown (7.5YR 5/8) organic coats in root channels and/or pores; 25% pebbles; 40% cobbles; 10% stones; dominantly quartzite rock fragments; approximately 5% of the rock fragments are mafic intrusives; clear wavy boundary. (Sample no. WYGL0154)

2CB. 55–83 cm; olive brown (2.5Y 4/4) and dark yellowish-brown (10YR 4/4) extremely cobbly loam; very pale brown (10YR 7/4) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine subangular blocky; soft, friable, sticky, slightly plastic; few very fine roots throughout and matted around coarse pebbles, cobblestones and stones; common very fine tubular pores; common discontinuous faint dark yellowish- brown (10YR 4/4) pressure faces on horizontal faces of peds; common patchy prominent strong brown (7.5YR 5/8) organic coats in root channels and/or pores; 25% pebbles; 40% cobbles; 10% stones; dominantly quartzite rock fragments; approximately 5% of the coarse fragments are mafic intrusives; clear wavy boundary. (Sample no. WYGL0155.)

3C. 83–108 cm; olive brown (2.5Y 4/4) and dark yellowish-brown (10YR 4/4) extremely cobbly loam; light reddish brown (2.5YR 6/4) dry; massive; slightly hard, friable, slightly sticky, slightly plastic; few very fine roots throughout; common very fine tubular pores; common continuous prominent strong brown (7.5YR 5/8) organic coats in root channels and/or pores; 25% pebbles; 40% cobbles; 10% stones; dominantly quartzite rock fragments; approximately 5% of the rock fragments are mafic intrusives. (Sample no. WYGL0156.)

SERIES: WYGL016

SOIL SURVEY # S86–56–001–016

LOCATION: Lat. 41° 22' 32" Long. 106° 15' 7"

Base Map Location (Appendix F): X = 16.8, Y = 8.2.

CLASSIFICATION: Loamy-skeletal, mixed Typic Cryoboralf

PHYSIOGRAPHY: Moraine in glaciated uplands

GEOMORPHIC POSITION: on middle third of component; backslope of sideslope

SLOPE: 20% plane, west facing

ELEVATION: 3274 m MSL

PRECIPITATION: Udic moisture regime

WATER TABLE DEPTH: None observed

PERMEABILITY: Moderately rapid

DRAINAGE: Well drained

STONINESS: CLASS 4

EROSION OR DEPOSITION: Slight

FAMILY CONTROL SECTION: 33 to 68 cm

RUNOFF: Rapid

PARENT MATERIAL: glacial till from quartzite material

DIAGNOSTIC HORIZONS: 4 to 0 cm Ochric; 0 to 33 cm Ochric; 0 to 33 cm Albic; 33 to 68 cm Argillic

DESCRIBED BY: Hopper, Roswall SAMPLE DATE: 09/86

NOTES: pit is located on south side of moraine below and east of East Glacier Lake; spruce-fir forest vegetation; site is associated with one of the University of Wyoming lysimeter installations.

Oi. 4–3 cm; dark reddish-brown (5YR 2/2) fibric material consisting of undecomposed and partially decomposed forest litter; very dark grayish-brown (10YR 3/2) dry; loose, nonsticky, nonplastic; abrupt smooth boundary. (Sample with Oa in sample no. WYGL0161.)

Oa. 3–0 cm; dark reddish-brown (5YR 2/2) and dark reddish-brown (5YR 3/2) sapric material consisting of well-decomposed forest litter; very dark grayish-brown (10YR 3/2) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine granular; soft, very friable, nonsticky, nonplastic; many very fine and fine roots and common medium roots throughout; abrupt smooth boundary. (Sample no. WYGL0161.)

E. O–12 cm; brown to dark brown (7.5YR 4/2) very gravelly silt loam; light brownish-gray (10YR 6/2) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine granular; soft, friable, slightly sticky, slightly plastic; many very fine, medium and coarse roots throughout; common very fine tubular pores; 35% pebbles; 10% cobbles; 5% stones; dominantly quartzite rock fragments; approximately 5% of the rock fragments are mafic intrusives; clear wavy boundary. (Sample no. WYGL0162.)

EB. 12–33 cm; brown to dark brown (7.5YR 4/2) and yellowish-red (5YR 4/6) very gravelly silt loam; very pale brown (10YR 7/3) dry; moderate medium subangular blocky structure parting to moderate fine platy parting to moderate very fine granular; soft, fri-

able, slightly sticky, slightly plastic; many very fine and fine roots and few to common medium and coarse roots throughout; many very fine and fine roots matted around coarse pebbles, cobblestones, and stones; common very fine tubular pores; few discontinuous distinct yellowish- red (5YR 4/6) organic coats or clay films in root channels and/or pores; few discontinuous faint yellowish-red (5YR 4/6) clay films on vertical and horizontal faces of peds; 35% pebbles; 10% cobbles; 5% stones; dominantly quartzite rock fragments; approximately 5% of the rock fragments are mafic intrusives; clear wavy boundary. (Sample no. WYGL0163.)

BE. 33–47 cm; brown to dark brown (7.5YR 4/4), brown (7.5YR 5/4), and light brown (7.5YR 6/4) very gravelly silt loam; pale brown (10YR 6/3) and very pale brown (10YR 8/3) dry; moderate medium subangular blocky structure parting to moderate fine platy parting to moderate very fine granular; soft, friable, sticky, slightly plastic; common very fine and fine roots and few medium roots throughout; common very fine and fine roots matted around coarse pebbles, cobblestones, and stones; common very fine tubular pores; common discontinuous distinct yellowish-red (5YR 4/6) organic coats or clay films in root channels and/or pores; common discontinuous distinct brown (7.5YR 5/4) clay films on vertical and horizontal faces of peds; 40% pebbles; 10% cobbles; 5% stones; dominantly quartzite rock fragments; approximately 5% of the rock fragments are mafic intrusives; clear wavy boundary. (Sample no. WYGL0164.)

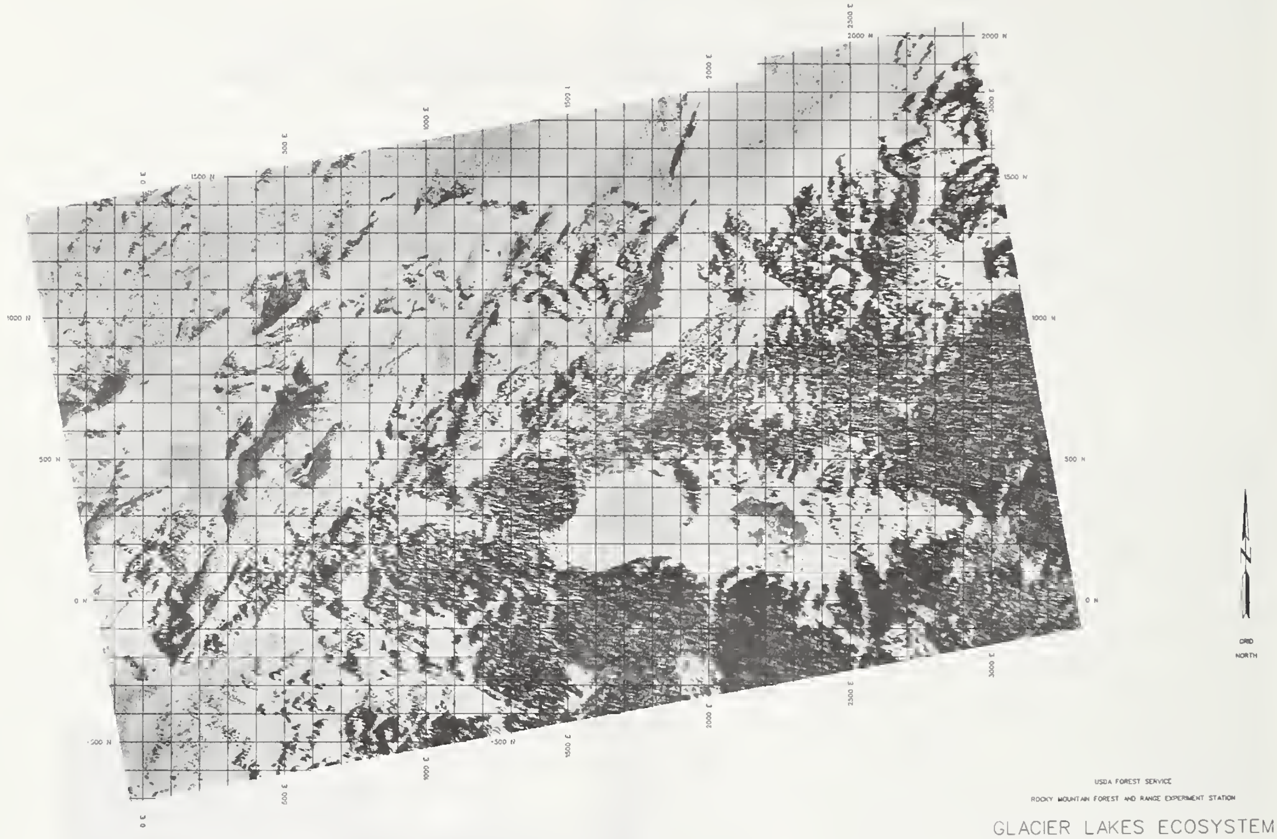
Bt. 47–68 cm; brown to dark brown (7.5YR 4/4) and light brown (7.5YR 6/4) extremely stony loam; light yellowish-brown (10YR 6/4) and very pale brown (10YR 8/3) dry; moderate medium subangular blocky structure parting to moderate fine and moderate very fine granular; soft, friable, sticky, slightly plastic; common very fine and fine roots throughout and matted around coarse pebbles, cobblestones, and stones; common very fine tubular pores; common discontinuous distinct brown to dark brown (7.5YR 4.4) clay films on vertical and horizontal faces of peds; 25% pebbles; 15% cobbles; 35% stones; dominantly quartzite rock fragments; approximately 5% of the rock fragments are mafic intrusives; clear wavy boundary. (Sample no. WYGL0165.)

BC. 68–102 cm; brown to dark brown (7.5YR 4/4) and yellowish-brown (10YR 5/4) extremely stony loam; light yellowish-brown (10YR 6/4) and reddish-yellow (7.5YR 6/6) dry; weak medium subangular blocky structure parting to moderate fine and moderate very fine granular; soft, friable, slightly sticky, slightly plastic; few very fine and fine roots throughout and matted around coarse pebbles, cobblestones, and stones; common very fine interstitial and tubular pores; common discontinuous distinct brown to dark brown (7.5YR 4/4) clay films on vertical and horizontal faces of peds; 20% pebbles; 25% cobbles; 40% stones; dominantly quartzite rock fragments; approximately 5% of the rock fragments are mafic intrusives. (Sample no. WYGL0166.)

Appendix F

100-Meter Grid Orthophoto Maps

Orthophotographs of GLEES in winter and in summer, with 100 m grid overlay. The grid can be used to precisely locate monitoring sites and facilities at GLEES.



USDA FOREST SERVICE
ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

GLACIER LAKES ECOSYSTEM
EXPERIMENTS SITE
RWU4452
ORTHOPHOTO MAP
WINTER

METERS

PREPARED BY:
AERO-METRIC ENGINEERING
FORT COLLINS, COLORADO

DATE OF PHOTOGRAPHY 05-13-88

The United States Department of Agriculture (USDA) prohibits discrimination in its programs on the basis of race, color, national origin, sex, religion, age, disability, political beliefs and marital or familial status. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (braille, large print, audiotape, etc.) should contact the USDA Office of Communications at (202) 720-5881 (voice) or (202) 720-7808 (TDD).

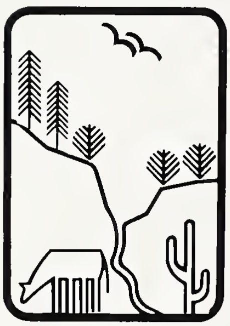
To file a complaint, write the Secretary of Agriculture, U.S. Department of Agriculture, Washington, D.C. 20250, or call (202) 720-7327 (voice) or (202) 720-1127 (TDD). USDA is an equal employment opportunity employer.

Rocky Mountains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.



Southwest

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Great Plains

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota

*Station Headquarters: 240 W. Prospect Rd., Fort Collins, CO 80526